Introduction - Manures and Fertilizers

The word "Manure" is originated from the French word "MANOEUVRER" which refers to "work with soil". The word Manure is also originate from Latin word "Manu" (hand) and operate (to work).

Manure:

Manures are the substances which are organic in nature, capable of supplying plant nutrients in available form, bulky in nature having low analytical value and having no definite composition and most of them are obtained from animal and plant waste products.

Fertilizer:

A fertilizer can be defined as a mined or manufactured material containing one or more essential plant nutrients in potentially available forms in commercially valuable amounts.

Differences between manures and Fertilizers:

S.No.	Manures	Fertilizers
1	Organic in nature	Inorganic in nature
2	Slow acting	Quick acting
3	Having low analytical value	Having high analytical value
4	Having no definite chemical composition	Having definite chemical composition
5	Obtained from plant , animal and human resources	Mined or manufactured
6	Improves physical properties of soils	Don't improve the physical properties of soils
7	Supply almost all major, minor and micronutrients.	Supply one or very few plant nutrients.
8	Derived from French word 'MANOEUVRER' to work with soil	Derived from Latin word Fertil (means Fertile)
9	Bulky in nature	Non-bulky in nature

Manuring:

Manuring is the process of increasing the productive capacity of land by adding plant foods to the soil in different forms.

Classification of Manures with examples

MANURES

A) Bulky organic manures
(Slow acting with large quantity of organic matter)

1. Farm Yard Manure (FYM)
- i) Cattle manure
- ii) Sheep manure
- iii) Poultry manure
- iv) Pig manure
- v) Biogas slurry

2.Composts
- i) Rural or village compost
- ii) Urban compost
- iii) Vermicompost

3.Green manures
- i) Green manuring in-situ
- ii) Green leaf manure

4. Agro-based Industry wastes
- i)Press mud cake
- ii)Cotton dust

5. Human habitation waste
- i) Night soil

6. Municipal wastes
- i)Municipal rubbish
- ii)Street sweepings
- iii)Market wastes

B) Concentrated organic manures
(Quick acting with small quantity of organic matter)

1. Plant origin

a) Edible oil cakes (suitable for cattle and poultry feeding)
- i) Mustard cake
- ii) Ground nut cake
- iii) Sesame cake
- iv)Linseed cake

b) Non –edible oil cakes(suitable for crop fertilization)
- i) Castor cake
- ii) Neem cake
- iii) Sunflower cake
- iv) Mahua cake
- v) Karanj cake

2).Animal origin
- i) Bone meal
- ii) Blood meal
- iii) Horn meal
- iv) Meat meal/ Tankage
- vi) Fish product-Fish meal
- vii) Bird product- Guano(excreta and dead bodies of sea birds)

Importance of Manures in Soil Fertility Management

A) Bulky organic manures:

The bulky organic manures are organic in nature and required in huge amounts. All these bulky orgaic manures are bulky in nature and supply i) plant nutrients in small quantities and ii) organic matter in large quantities. Eg. FYM, Composts, Green manures, Sewage sludge. Of the various bulky organic manures FYM, Compost and Green manures are widely used. The effect of bulky organic manures on soils is three fold.

Since these manures contain plant nutrients, they have direct effect on plant growth like any other commercial fertilizer. Bulky organic manures contain nutrients in small quantities, therefore large quantities of these are needed. Besides the major nutrients, they also contain traces of micro-nutrients. Bulky organic manures increase organic matter content and hence improve the physical properties of soil. This effect is very important in case of most of our arable land. Such manures increase the humus content of soil and consequently water holding capacity of sandy soils also increased and the drainage of clayey soils is improved.

Bulky organic manures provide food for soil microorganisms. This increases the activity of microbes which in turn help to convert unavailable plant nutrients into available form.

Organic manures have been the traditional means of improving soil fertility. The organic matter that is applied thorough organic manures has very complex effect on soil and on plant growth. The main effects are

Effect of organic matter on soil properties:

1. Improvement of soil physical properties:-
    - Improvement of soil structure
    - Improvement of water holding capacity
    - Improvement of soil aeration
    - Reduction of soil loss through erosion
2. Improvement of chemical properties:-
    - Supply of essential plant nutrients in balanced ratio
    - Slow release of nutrients
    - High residual value
3. Improvement of biological activity:-
    - Stimulation of soil fauna and flora

B) Concentrated organic manures:

Like bulky organic manures, these organic manures contain plant nutrients and considerable amount of organic matter. They have direct effect on plant growth. Nitrogen content is higher in concentrated organic manures and varied from 2.5 per cent in mahua cake to 7.9 per cent in decorticated safflower cake. In addition to nitrogen all the oil cakes contain P_2O_5 (0.8 to 2.9 %) and K_2O (1.2 to 2.2%) since they contain nitrogen in relatively large quantities, they are usually classified as organic nitrogenous manures. By virtue of this high nitrogen content they enrich the nitrogen status of soil

Bulky Organic Manures

Bulky organic manures are those materials of plant and /or animal origin, which when added to the soil have tendency to decrease bulk density and to increase soil volume ,thus providing better physical conditions for plant growth especially in coarse textured soils and also provide essential nutrients in smaller quantities than the chemical fertilizers.

Characteristics of bulky organic manures:

1. Organic materials are relatively poorer in concentration of plant nutrients.
2. These materials possess wider C:N ratio and C:S ratios and so supply energy needed for microorganisms.
3. The mineral nutrients that are available in the organic materials become available to plants after mineralization.
4. Judicious combination of organic and inorganic manures is quite essential to maintain fertility status.

Examples : 1. FYM, 2. Composts, 3. Green manures, 4. Pouderette, 5. Biogas slurry, 6. Sewage or sludge, 7. Molasses and 8.Vermicompost

FARM YARD MANURE (Cattle manure)

The physical composition of cattle manure is called Farm Yard Manure, which consists of dung and urine of cattle and the litter, a bedding material like hay, straw used for cattle.

Cattle manure is slow acting, bulky organic and however is a low analysis fertilizer, obtained from dung and urine of farm animals mixed with litter and other miscellaneous farm wastes.

Constituents of FYM:

Dung: The dung is a solid excreta voided by farm animals, which represents the undigested and non-digestible portion of the animal feed. Besides, it is also admixed with digestive juices, tissues of alimentary canal, microbial cells etc.. The percentage of moisture varies from 70-80 per cent.

Urine: The liquid excreta of farm animals, which is composed essentially of the by products of nitrogen metabolism of farm animals. It also consists of 90 per cent water with small amounts of urea, hippuric acid, sulphates of sodium and potassium and also chlorides and phosphates of Ca, Mg, K and Na etc.,

Litter: Litter is a variable mixture consisting of straw, leaves, stems used as bedding material for cattle during their rest and eventually absorbs the urine and adds carbonaceous matter in the manure to facilitate decomposition.

Quality and composition of FYM:

The quality of manure and chemical composition in particular is highly variable as the following factors affect the product.

1. Kind of animal
2. Age and condition of the individual animal
3. Quality and quantity of feed consumed
4. Kind of litter used
5. Collection and
6. Storage of manure

1) Kind animal:

The quality of manure depends on the class of manure. viz., cattle, horse manure. With in the same class, quality varies according to the kind of animal, such as milch cattle, dry cattle, work cattle, breeding bulls etc., By and large the dung and urine from animals, which assimilates less (little) for their maintenance and production will provide better quality manure .

2) Age and condition and individual animal:

Growing animals, milch cattle, pregnant or carrying cattle utilize much of the ingredients in the feeds for building up their growing bodies, milk production and for the development of the embryo [calf]. Old or adult animals kept on light work or no work utilize little from feeds and as such, most of nitrogen is voided through urine and dung. Eventually, the adult old cattle provide better manure.

3) Quality and quantity of feed consumed:

Nutritious and protein rich feeds like oil cakes enriches the nitrogen content to the resulting manure than the bulky feeds like straw and green grass. Animals fed on concentrated feeds yield better quality manure.

4) Kind of litter used:

The quality of manure depends to a considerable extent on the nature of litter used. Remnants of leguminous hays (*Bhusa*) give richer manure than usual straws.

5) Collection of manure:

The method adopted for collection of dung, urine and litter primarily decide the quality of manure as the loss of nutrients particularly nitrogen occurs from the time urine and dung are voided by cattle. The quality of manure depends upon the methods of collection viz., Byre, Lose box and Dry earth systems.

Byre system:

Cattle are stalled in a shed with a non absorbent floor provided with necessary slope towards the urine drains. The urine that flows into the drains is collected into a covered tank .From where it is periodically removed and sprinkled on the manure stored in a covered pit .The urine which is an important component of FYM can be properly stored (conserved) in this system. The perfect cleanliness and hygienic conditions of the stalls as well as cattle can be maintained in this system.

Dry earth system:

The floor of the cattle shed is well rammed and compacted .Layers of fine sand ,red earth of loamy soil are spread as an absorbent for urine .The wet portions are properly covered with dry layers or any of the above materials and once a week the surface layer is removed and dumped in the manure pit. Available saw dust, paddy husk, groundnut shell, paddy winnowed dust would serve the purpose very well compared to the earth absorbents. This system is popular and extensively adopted in rural parts being cheep, convenient and practicable under the existing rural conditions in India.

6) Storage of Manure:

Method of storage of manure influences the quality of manure to a large extent. During storage the manure undergoes fermentative changes, decomposition which leads to loosing its original structure and shape. There are three methods of storage viz., pit method and heap method and covered pit method.

A) Pit method (Below ground level):

In this method, the manure is stored in a pit with non –absorbent bottom and sides. The pit is provided with a bund at the rim of the pit to prevent the surface run-off of waters during rainy season .The dimensions of the pit can be variable depending on the quantity of dung, urine and litter produced on the farm per day .The losses also occur in this method due to exposure to sun and rain, but it is relatively a better method than the heap method.

B) Heap method (Above the ground level):

This is the most common method adopted in Indian villages. Manure is heaped on the ground preferably under the shade of a tree. Ideal procedure is to dump the dung first and to cover it with litter soaked urine. This is further covered with a layer of litter /ash / earth to prevent the loss of moisture and to avoid direct exposure to sun. It is also desirable to put up a small bund around the base of the heap to protect against surface run-off washing out the manurial ingredients. It is beneficial to cover the exposed portion of the heap with Palmyra leaves or any other available material.

The maximum losses of nutrients occur in this method of storage, resulting in poor quality manure. Direct exposure to the vagaries of climate such as sunshine and rainfall causes looseness and dryness of manure, which hasten the losses of nutrients and rapid oxidation of organic matter.

C) Covered pit method:

Of all the methods described, it is the best method. In this method, the bottom and sides of the pit are made non-absorbent by granite stone lining. The pit is also provided with a bund of 1½ feet height to prevent surface flow of water (Rain water) and a suitable cover by way of roofing with locally available materials like Palmyra or phoenix leaves etc., organic matter and 8nutrient losses can be effectively controlled in this method of storage in order to obtain better quality manure [FYM: 0.68 % N- 0.5%P – 1 % K].

Improved methods of handling farm yard manure

It is practically impossible to check completely the loss of plant nutrients and organic matter during handling and storing of FYM .However, improved methods can be adopted to reduce such loss. Considerably, they are.

A) Trench method of preparing FYM:

This method has been recommended by **C. N. Acharya**. The manure preparation should be carried in trenches of suitable size, say 20-25 feet length, 5-6 feet breadth and 3-3.5 feet depth .All available dry litter and refuse from the farm and the houses should be heaped up near the cattle shed and portions of litter mixed with earth if available should be spread in the shed in the evening @ 2.26 kg per animal for the absorption of urine. The litter should be localized in the areas where urine generally drops and soaks into the ground. Every morning the urine soaked litter and dung should be well mixed and then taken into the manure trench. A section of 3 feet length of the trench from one end should be taken up for filling with daily collection of refuse from cattle shed. When the trench is filled to the height of 1.5 to 2.0 feet above ground level, the top is made dome shaped and plastered with cow dung mixed with soil. The manure becomes ready for about three months .By this time the next 3 feet length of the trench being filled up. Generally 2 such trenches would be needed for three to four cattle. It is possible to prepare by this process 250-300 cubic feet of manure (3 to 5 tones or 10-12 cart loads) per animal. The FYM should be enriched by addition of super phosphate @ 30-40 kg per trench before application to fields. The content of nitrogen is at least 0.7 to 0.8 % N on the fresh weight basis or 1.4 to 1.6 % N on dry weight basis.

Losses of Nutrients From FYM During Collection and Storage

There are two types of losses of FYM, which are as follows.

1. Losses during handling
2. Losses during preparation and storage

Losses during handling:

FYM consists of two original components such as i) dung (solid portion) and ii) urine (liquid portion) which are subjected to different losses in different ways.

Both the components contains N, P_2O_5 and K_2O. Approximately, half of nitrogen and potash in dung and other half in urine. Whereas nearly all the phosphorus (96%) in the solid portion. To conserve N, P_2O_5 and K_2O, it is most essential that both the parts of cattle manure are properly handled and stored.

i) Losses of dung: Dung is a valuable manure. Still larger portion is dried in dung cakes and burnt as fuel .Besides this large portion of cattle excrements is dropped out side the cattle shed, when the animals are grazing on the uncultivated lands. This can be used for preparation of FYM.

ii) Losses of urine: Urine contains nitrogen and potassium in large portions. But there is no good method of preserving the urine in our country. In our country most of the cattle sheds have uncemented or *kachha* floor and the urine gets soaked in the soils of *kachha* floor of the cattle shed and the large quantities of nitrogen are thus lost through the formation of gaseous ammonia as follows.

$$\underset{\text{Urea in urine}}{CO(NH)_2} + 2H_2O \rightarrow \underset{\text{Ammonium carbonate}}{(NH_4)_2CO_3}$$

$$(NH4)2\ CO3 + 2H2\ O \rightarrow 2\ NH4OH + \underset{\text{Carbonic acid}}{H2\ CO3}$$

$$\underset{\text{Ammonium hydroxide}}{NH4OH} \rightarrow \underset{\text{Ammonia}}{NH3\uparrow + H2O}$$

B. Losses during preparation and storage:

Cow dung and other farm wastes are collected daily and these are accumulated in manure pit in open space for months together .The manure remain exposed to sun and rain during this period .Due to this effect the nutrients are lost in following ways.

i) By leaching:

Nutrients of manures are water soluble and these are liable to get washed by rain water .The leaching loss of nutrients will vary with the surface exposed, the intensity of rain fall and the slope of the surface on which manure is heaped .The leaching loss may be prevented by erecting a roof over the pit.

ii) By volatilization:

During storage, the urine and dung are decomposed and considerable amount of ammonia is produced. The ammonia combines with carbonic acid to form ammonium carbonate and bicarbonate, which are rather unstable and gaseous ammonia may be readily liberated and passes into atmosphere as indicated in the following equations.

I. Urea and other nitrogenous compounds in urine and dung by microbial decomposition liberates NH_3 (Ammonia)

II. $2\ NH_3 + H_2CO_3 \rightarrow (NH_4)_2CO_3$

III. $(NH_4)_2\ CO_3 + 2H_2O \rightarrow 2\ NH_4OH + H_2CO_3$

IV. $NH_4OH \rightarrow NH_3 \uparrow + H_2O$

Ways to minimize these losses from FYM during handling

1. Adopt trench method as suggested by C.N.Acharya for handling of dung and urine.
2. Use of Gobar gas plant: 50 % of dung is made dung cakes and burnt as fuel for cooking. The use of cow dung in gas plant produces a combustible gas, methane used as fuel gas which, is an improved method of handling FYM.
3. Adopting covered method of storing FYM: Nutrients losses can be effectively controlled by this method
4. Adoption of BYRE system in collection of FYM
5. Proper field management of FYM: During spreading of FYM in the field in small heaps leads to loss of nutrients from it .It is advisable to spread the FYM before ploughing.
6. Use of chemical preservatives:

Chemical preservatives are added to FYM to decrease nitrogen losses. To be most effective, the preservatives are applied in the cattle shed to permit direct contact with the liquid portion of excreta or urine .This has to be done because the loss of nitrogen from urine starts immediately.

Commonly used preservatives are 1) Gypsum 2) Super phosphate .It is recommended that 450 g to 900 g of super phosphate should be applied per day per animal in the cattle shed .Super phosphate should be applied in places where animal pass urine . The reaction of gypsum with ammonium carbonate (intermediate product from decomposition of urea present in urine) is

$$(NH_4)_2\ CO_3 + CaSO_4 \rightarrow Ca\ CO_3 + (NH_4)_2\ SO_4$$

With this reaction ammonium carbonate is converted to $(NH_4)_2 SO_4$. As long as manure is in moist, no loss of ammonia will occur but if dried the chemical reaction is reversed and loss of ammonia may occur. Use of gypsum also prevents the bad smell caused by production of ammonia in the cattle sheds. As such in Indian conditions use of gypsum to decrease N loss does not offer practical solution.

Super phosphate has been extensively used as a manure preservative. Since ordinary superphosphate contains up to 50to 60 per cent gypsum besides mono calcium phosphate. The reaction with ammonium carbonate is given below

$$2CaSO_4 + Ca(H_2PO_4) + 2(NH_4)_2CO_3 \rightarrow \underset{\text{(TCP)}}{Ca_3(PO_4)_2} + 2(NH_4)_2SO_4 + 2H_2O + 2CO_2$$

In this reaction, tricalcium phosphate is formed which does not react with ammonia sulphate when manure becomes dry as such there is no loss of ammonia.

STRAW:

Straw is sometimes left on the field as waste product from the harvest. It is useful as organic fertilizer especially on farms without live stock. Although straw contains few nutrients, it yields decomposable organic matter (Eg. Cellulose).Fertilization with straw thus supplies energy [1 kg straw = 12 Kilo Joules energy] ,but mainly improves the structure of medium and heavy soils .The nutrient contents of straw vary but are small in any case viz., 0.5 % N – 0.1 % P – 1 % K and dry matter of 85 %. The C:N ratio is very large about 100:1 .This may cause inhibition of decomposition because the microbes lack in nitrogen ,[Compensating supplies of N about 1% of the quantity of straw] is thus required.

Compost and rural composting

Dry and fresh plant tissues and also animal wastes can be introduced directly into or on the soil. They are then decomposed at varying speeds, but have only slight and sometimes detrimental effects and bring about scarcely any substantial soil improvement. Process known since antiquity make it possible to convert such wastes into useful agents for soil improvement i.e., compost.

The word compost is derived from the Latin word "COMPONERE" to mean put together.

Compost:

Compost is a product of decomposition of plant and animal wastes with various additives. The compost had the largest variation of all organic material ranging from neglected garbage dumps to carefully composted and treated substances with high fertility.

Composting:

Composting is a process of converting organic matter in to manure in a short time by accelerating fermentation process under controlled conditions is called composting.

The organic material that is usually handled for composting are waste vegetative material such as spoiled straw, peanut hulls, saw dust, dried leaves etc., stubbles, chilli plants, cotton stalks, tobacco stems, weeds, municipal rubbish etc., according to availability.

The following basic rules are important for the production of good quality compost:

1. The purpose of composting is to convert organic matter into growth promoting substances, for sustained soil improvement and crop production.
2. The organic matter is partially decomposed and converted by microbes. These microbes require proper growth conditions, for their activity .i.e moisture content: 50 % and 50 % aeration of total pore space of the composting material .This is achieved through stacking and occasional turning over. Microbes also need sufficient nitrogen for synthesizing their body cells [the optimum C:N ratio of the composting material is 20:1 to 30:1]
3. Soil microorganisms constitute sufficiently to the decomposition of organic matter through their continuous activities. The majority of these soil animals provide optimal conditions in their digestive track for their synthesis of valuable permanent humus and stable soil crumbs. A typical compost earthworm is *Eisenia foetida*.
4. Certain additives accelerate the conversion and improve the final product. The materials such as lime, earth, gypsum, rock phosphate act as effective additives .The addition of nitrogen (0.1 to 1 %) is important in case of large C:N ratio of the composting material. Addition of lime (0.3 to 0.5 %), if sufficient lime is not present. The preparation of compost takes 2-3 months. The composition of compost varies with in wide limits.

The following average values are rough estimates

Composition of compost (Rough)

S. No.	Constituent	Percentage
1	Dry matter	30-50
2	Organic matter	10-15
3	N	0.3
4	P	0.1
5	K	0.3

Methods of composting

The process of composting was first initiated in England during the period of First World War (1914 -1918).

The various systems of composting are-

1. ADCO process (Agricultural Development Company)
2. Activated compost process
3. Indore process
4. Bangalore process
5. Coimbatore process
6. Rain -water compost
7. Rural compost
8. Urban compost
9. Mechanical compost and
10. Vermicompost.

1. ADCO process:

Agricultural Development Company was initiated, [A private concern operating at Harpenden, England] developed by **Hutchinson, H.B and Richards, E.H.** during 1914-1918, at Rothamsted Experimental Station, England.

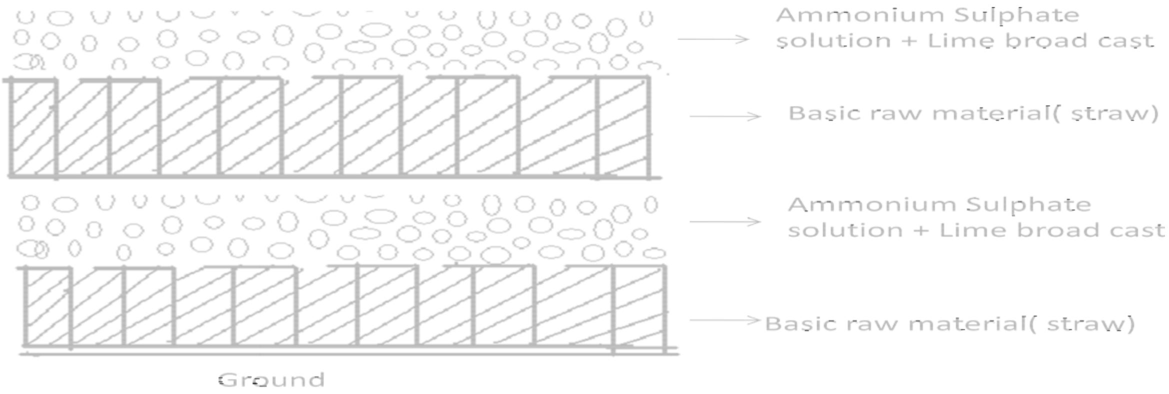
Materials needed:

1. Straw and other wastes -Basic raw material
2. Ammonium sulphate/Ammonium phosphate /Super phosphate/Muriate of potash Ground limestone/ urea - Starters

Procedure:

The basic raw material straw is spread in layers and sprinkled over with a solution of ammonium sulphate. Then powdered lime stone is applied as broadcast. Then another straw layer is put on. The piling of the layer is continued till a decent heap of convenient height is built up. After about 3 months of fermentation the resulting material is similar to FYM and hence called “synthetic FYM”

The ADCO process was patented and concentrated starters were put in the market with the trade names of ADCO accelerator and ADCO complete manure with full direction for their use.



2. Activated compost process:

This method was developed by **Fowler and Ridge in 1922** at Indian Institute of Science, Bangalore

Materials needed:

1. Basic raw materials (Straw and farm wastes)
2. Starters: a) Cow dung b) Urine c) Night soil d) Sewage and sludge

Procedure:

In this process the basic raw material for composting straw and other farm Wastes is treated with mixture of cattle dung and urine as decoction. So that every portion of mass comes in contact with the inoculants (dung + urine) and fermentation takes place evenly. On piling up in a heap of 3 feet or 4 feet height and turning over form time to time, keeping moist with dung and urine decoction, very high temperatures attained. When the temperatures beginto drop at the end of one week. The volume of the material gets reduced. Further quantity of the basic material is added onto the heap. About 25 % of the new materials should be added a t one time and thoroughly mixed with starters (dung +urine decoction) at intervals as before. If properly carried out, the compost will be read y in 5-6 weeks. Night soil and se wage and sludge are also used as starters in this method.

3. Indore process:

This process is developed in India by **Howard and Ward** at the Indian Institute of plant Industry, Indore

Materials needed: a) Straw or organic farm wastes as basic raw materials
b) Cattle dung as starter (urine, earth and wood ashes)

Procedure:

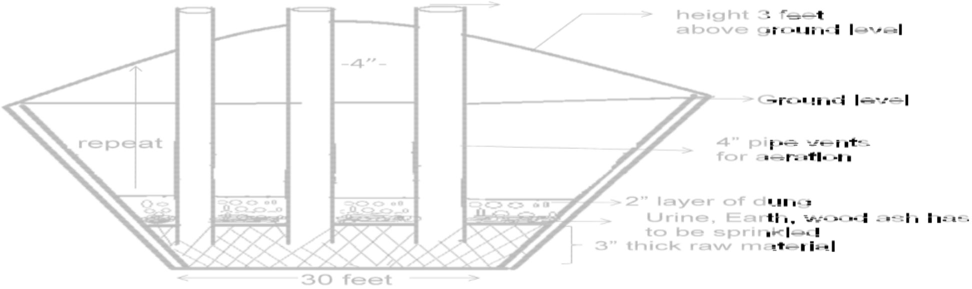
A compost pit of dimensions of 30 x 14 x 3 feet with sloping sides (narrow at bottom and at wide surface) is prepared and the raw material is spread in layers of 3” thickness. A mixture of urine, earth, and wood ashes is sprinkled and this is followed by 2” layer of dung. The pit is filled up this way until the material occupies a height of 3 feet above the ground level. As air can conveniently penetrate only to a depth of 1.5 to 2.0 feet extra aeration has to be provided, which is done by means of artificial vents (holes) of 4” diameter pipe for every 4 feet length of the pit. The pit is watered twice a day i.e., morning and evening with rose can. The material is turning over 3 times, i.e.,

First – at the end of the first fort night
Second – at the end of the second fort night
Third – when the material is two months old in the process of composting.

Observations:

1. After 10 days of composting the following things happens
   a) Synthesis of humus begins i.e., development of fungi and the height of the material is reduced by half
   b) Check anaerobic decomposition, as indicated by the foul smell and fly breeding
   c) If there is an anaerobic decomposition, turn over material for proper aeration
   d) If insufficient fermentation, hasten by watering the material.
2. At the end of two months
   a) Fungal activity is over
   b) Materials become dark
   c) Now the bacterial aeration takes place
   d) Stock the material on the ground after 2 months .So 25 % of additional free nitrogen will be fixed from atmosphere.

Compost is ready by 3-4 months. One cattle pair produced 50-60 cartloads per year.



4. Bangalore process [Aerobic and anaerobic process]:

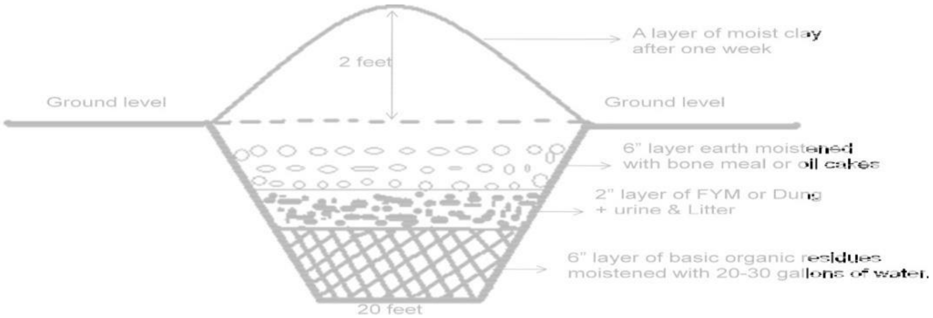
This process of composting was developed by **Dr. C. N. Acharya** in the year 1949.

1. Basic raw material used: Any organic material
2. Starters or inoculants [Undecomposed]: FYM or mixture of dung and urine or litter
3. Additives: Bone meal or oil cakes, wood ash

Procedure [Pit size: 20 x 4 x 3 feet]:

The basic raw material is spread in a pit of 20 x 4 x 3 feet dimensions to a depth of 6 " layer, moistened with 20-30 gallons of water if the material is dry. Over this FYM or preferably a mixture of dung, urine and litter (un-de composed) from the cattle shed is placed as a layer of 2" thickness. It is again covered on the top with a layer of earth to a thickness of 6 ". It is beneficial to mix the earth with bone meal or oilcakes, wood ash etc., to improve manurial value of the compost .T he piling of layers is continued till the heap raises above the ground level to a height of 2 feet .Then the heap is kept open for one week to facilitate aerobic decomposition. Later the heap is plastered with a layer of moist clay for anaerobic fermentation to occur. Fissures, or cleavages (cracks) that occur in the clay layer, have to be sealed off periodically. The compost will be ready in 4-5 months period starting from the day of preparation. This process is called as aerobic and anaerobic decomposition of compost.

In this process the basic raw material is not so well decomposed as in the other methods. But organic matter and N contents are well conserved. The number of turnings are reduced. The out turn of the compost is relatively greater and cheapest process.

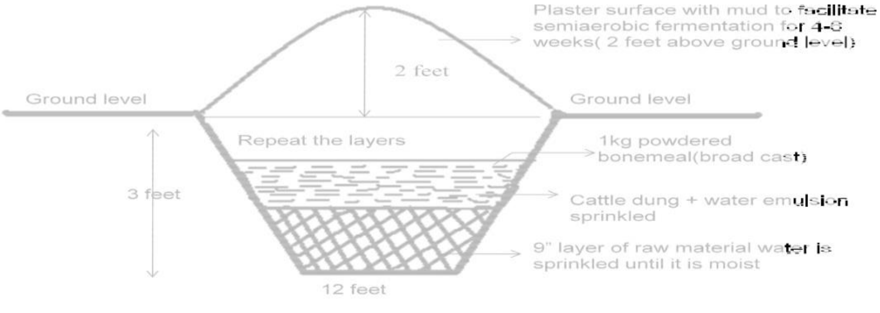


5. The coimbatore process:

1. The basic raw materials: Raw organic matter
2. Starters: Powdered bone meal and cattle dung and water emulsion prepared by mixing
3. Dung in water @ 5-10 kg dung in 5 to 10 liters water.

Procedure [Pit:12 x 6 x 3 feet]:

The basic raw material loosely spread [Pit:12 x 6 x 3 feet] to a depth of 9" and water is sprinkled till the entire material is moist. Then about one kg of powdered bone meal is broadcasted uniformly above the layer and above this an emulsion of 5-10 kg of fresh cattle dung in 5-10 liters of water is applied .Repeat this process until a heap 2 feet above ground level is formed .Then the entire exposed surface area of heap is plastered with mud to facilitate semi-aerobic fermentation which would takes place for above 4-6 weeks depending upon the nature of the raw material .After 4-6 weeks ,the mud plaster is removed to permit aerobic fermentation . If the heap has sunk unevenly which is a sign of defective fermentation, the material is reheaped after forking and moistened. The decomposition is complete in 3-4 months and is fit for application to the field.



6. Rain watered compost:

In dry areas where it is difficult to obtain water for watering, the composting can be done with the aid of rain fall.

The compost heap is built up as usual before the rains set in. The turnings are given during the rainy period at the end of rains the material will be ready for application. About 400 mm rain fall received in 3-4 months is considered sufficient.

7. Rural compost:

Compost prepared using farm organic wastes and fresh dung and /or urine soaked earth as starter is called as Rural Compost. This is within the reach of farmers, as they can individually prepare the compost in their farm sheds.

Procedure:

Composting can be done in a pit size of 3 x 6 x 3 feet size located on an elevated place. Even length and width are adjustable depending upon the raw material available .Keep the sides of the pit slanting .When a number of pits are dug, keep 12 feet gap between the pits for facilitating turnings .Locate the compost pits away from the civilians areas.

Basic raw material: 1) Green succulent, non-woody and non-fibrous material (12"thick)
2) Dry materials like sugarcane trash, stubbles etc., (3" thick)
3) Starter: Dung and water

Neutralizing agents for organic acids: Bone meal is preferred to ash as it provides Ca and also phosphate, which are desirable constituents in the final product.

The organic material is spread in layers. The thickness depends upon compost ability of materials. Green succulent non-woody materials can be laid in 12 " layer while tough woody materials like sugarcane trash and stubbles are spread in 3" layer. Bone meal or ash is sprinkled in a thin layer over the material to provide the base for neutralizing organic acids produced during the decomposition .Dung and water is then sprinkled over the layer. Dung functions as starter while the water provides the moisture. The layers are thus built up to a height of one foot above the ground level .It is desirable to cover the surface of the heap with a layer of earth. Periodically watering is done.

Precautions;

1. Over watering creates anaerobic decomposition.
2. Turnings are necessary to hasten the aerobic decomposition
3. After turning the compost must be re-heaped and covered
4. Use the compost immediately
5. It is to be preserved by providing suitable cover
6. The compost will be ready by three months to one year depending upon material (Sugarcane trash –late).

8. Urban compost:

Compost prepared by local bodies ,municipalities, corporations etc., with their out put of street sweepings, municipal rubbish etc., as organic matter using night soil as starter is called urban compost

Methods of urban composting:

I. Method of urban composting:

Using municipal or town rubbish as basic raw material and night soil as starter. Sprinkling of copper sulphate powder between layers will put down the offensive odour due putrefactive fermentation of the material, yielding foul smelling organic compounds called Mercaptans.

II. Method of composting:

Night soil and rubbish are mixed in 1:4 ratio .Copper sulphate is added between layers at the rate of one kilogram for every 400 kg o f the mixture and the mixture is racked up to heaps of convenient size.

The heaps are moisned and racked up for every fort night and rebuilt. During the period of two month s, the manure will be ready for use. The product is dry and powdery, free from foul smell.

III. Method of composting:

Town refuse is he aped into a pit of dimensions of 8 x 4 x 4 feet. A groove measuring 6x1 x 1 feet is made at the top in the centre and is filled up with night soil and covered over with refuse. Heap is moistened daily with sullage water and racked up once a week. For six week s by which the decomposition pro cess would be complete and the product would be ready for use as manure.

IV. Method of composting:

The layer of waste material of 6" thick and night soil 2 " thick are altered; the final top layers will be the waste material. The heap is covered by 9" thick layer of soil. The material will be ready in about five months.

9. Mechanical compost:

In big cities like Delhi, Bombay, Calcutta (kolkat), while disposing the urban wastes face In numerable problems such as cost, land, labour for composting operations, involving human contact with filthy and obnoxious materials with a result mechanical composting is undertaken. mechanical composting can be undertaken at a central location and in s mall compact area .it is only mechanized composting which may prove effective in not only serving as a means of disposal of urban wastes but also of providing the country with large quantities of organic matter.

The advantage of mechanical composting-

1. Sanitary control with odour control device
2. Operational convenience, both in dry and wet seasons
3. Efficient recovery of discarded materials like metal, glass etc.,
4. High quality manure in a short period
5. Eliminates large anaerobic decomposition
6. Reduces preparation cost @ 10% for every tonne
7. Economically, cheaper than chemical fertilizers

10. Vermicompost technology:

An emerging technology for recycling of crop residues and other organic solid wastes is the utilization of earthworm technology to convert them into vermicompost.

Definition of vermicomposting:

Vermicomposting is a method of making com post, with the use of earthworms, which generally live, in soil eat biomass and excrete it in digested form. This compost is generally called vermicompost or wormicompost.

Definition of Vermiculture:

Vermiculture means scientific method of breeding and rising earthworms in controlled conditions.

Vermitechnology:

Vermitechnology is the combination of vermiculture and vermicomposting. Thus, earthworms can be used in the following areas.

1. For development of arable soils , turnover of soil, break down of plant organic matter aeration and drainage
2. For production of useful products like vermifertilizer and worm tissue for animal feed.
3. For maintenance of environmental quality and monitor of the environment for soil fertility, organic and heavy metal non-biodegradable toxic material pollution.

Vermiculture industry or vermicompost preparation:

1. Basic raw material: Any organic material generated in the farm like bhusa, leaf fall etc.,
2. Starter: Cow dung, Biogas slurry, or urine of cattle
3. Soil animal: Earth worms (Species: *Eisenia foetida*)

Favourable conditions of earth worms in the composting material:

1. pH: Range between 6.5 and 7.5
2. Moisture: 60-70 % of the moisture below and above range moderately of worms taking place
3. Aeration: 50 % aeration from the total pore space
4. Temperature: Range between 18 ^{0}C to 35 ^{0}C

Procedure:

It is mostly prepared in either pit or heap method .The dimensions either heap or pit are 10 x 4 x 2 feet .The length and width can be increased or decreased depending on the availability of material but not the depth because the earth worms activity is confined to the 2 feet depth only.

1st layer: Bedding material of 1" thick with soft leaves.

2nd layer: 9" thick organic residue layer finely chaffed material.

3rd layer: Dung + water equal mixture of 2" layer.

Continued the layer up to pile to ground level protect the worms against natural enemies like ants ,lizards ,snakes ,frogs ,toads etc., Maintain proper moisture and temperature by turnings and subsequent staking . At the day of 24th, 4000 worms are introduced in to the pit [1m^2 =2000 worms] without disturbing the pit by regular watering the entire raw material will be turned into the vermicompost in the form of worm excreta .The turnover of the compost is 75 % [the total material accommodated in the pit is 1000 kg; The out turn will be 750 kg]

Harvesting of the vermicompost from the pit:

Stop watering before one week of harvest. All the worms spread across the pit come in close and penetrate each other in the form of ball in 2 or 3 locations. Heap the compost by removing the balls and place them in a bucket, then the material is sieved in 2 mm sieve, the material passed through the sieve is called as vermicompost which is stored in a polythene bags [Note: Vermicomposting is done under thatched roof to protect worms against rain and sun]

Nutrient composition of vermicompost

S.No.	Nutrient	Content
1	Organic carbon	9.15 to 17.98 %
2	Total nitrogen	1.5 to 2.10 %
3	Total phosphorus	1.0 to 1.50 %
4	Total potassium	0.60 %
5	Ca and Mg	22.00 to 70.00 m.e / 100 g
6	Available S	128 to 548 ppm
7	Copper	100 ppm
8	Iron	1800 ppm
9	Zinc	50 ppm

Besides the above nutrients the vermicompost also contains following enzymes

Enzymes : Protease ,Lipase ,Amylase , Cellulose

Source: Kale (1983) in Vermicompost published in Agro bios Vol.I, No.XI, April, 2003 Edited by Purohit, S S

Conversion rates:

1000 earth worms may convert 5 kg waste material per day

1000 worms weighs about a kilogram

Advantages of composting over direct application:

1. There will be no immobilization in compost because of narrow C:N ratio
2. Application is easy, because the compost is humified and have a structure of crumb and granular.
3. It is hygienic, pathogens and weeds seeds are destroyed.
4. No loss of nutrients
5. It improves physical properties better than compost on soil application.

Differences between Aerobic and anaerobic decomposition

S.No.	Aerobic decomposition	Anaerobic decomposition
1	This takes place in the presence of O2	This takes place in the absence of O2
2	CO_2 is produced	Methane gas is produced
3	High water content is required	Less water content is required
4	Organic matter conserved is around 50-60 %	Organic matter conserved is around 75%
5	Around 25-50 % N is lost	20 % nitrogen is lost and more N is conserved
6	Temperature built up is more.Hence , pathogens weed seeds are killed	Pathogens are only killed due to antibiogens.
7	More labour is required for turnings and watering	Less labour is required
8	Time taken for decomposition is3-4 months	Time taken is 5-6 months

Penning, sewage, sullage, sludge and poudrette. Concentrated organic manures – oil cakes, blood meal, bone meal, horn meal, fish meal, meat meal & Guano

Penning

Keeping the boven animals (cattle and sheep) in the fallow land after the harvest of the last crop, throughout day /and or night provided with suitable food and shelter.

Types of penning: There are two types of penning

I. Cattle penning
II. Sheep penning

I. Cattle penning:

Keeping the cattle in the fallow land after harvest of the last crop, throughout day and night by providing them suitable food and shelter is called cattle penning. It is an ideal practice of collection and storage of dung and urine directly in the field. Urine is absorbed by soil while dung and litter are incorporated in situ. Losses in storage and collection are avoided by penning. Cattle are shifted from one field to other field once in 2-3 days for covering the maximum area. The dung and urine are uniformly spread and ploughed in it. The period congenial for cattle penning varies from 3-6 months i.e., form January –June or March to May depending on the extent of non cropping period.

Cattle penning is largely done for seedbeds of rice, root crops, sugarcane, vegetable etc., which require very heavy manuring. It is one of the oldest practice followed in India .About 800-1000 cattle per acre are penned which would be equivalent to 10-15 tonnes of cattle manure per acre [Composition (%): 0.5 N, 0.25P and 0.5K].

II. Sheep penning:

It is a popular practice followed in drier regions of Andhra Pradesh. Flocks of sheep and goats are penned in the fields during nights and allowed to graze during day time. The flocks are frequently disturbed during nights to increase droppings as they tend to void droppings when disturbed. The sheep penning is generally adopted for cash crops like vegetables, tuber crops, chillies and sugarcane.

Penning about 2000 heads per acre is the common practice. Sheep and goat manure are relatively lower in moisture content and higher in nutrient value than cattle manure. Average nutrient composition (%) of sheep and goat manure 1.93 N, 0.6 P and 1.90 K.

Some of the other organic (bulky) manures are obtained from the solid excretions from piggery, poultry and Human excreta (Night soil).

I. **Pig manure:** It is collected in dry state stored and extensively used whenever it is available for rice, banana, and vegetables. The percent nutrient composition is 3.7 N, 1.4 P and 0.3 K.

S.No.	Nutrients	Human excreta nutrients supply (kg/person /year)	Relative values in terms of cattle dung(kg /cow /year)
1	N	4.7	2.9
2	P2 O5	1.1	0.8
3	K_2 O	1.0	2.3

II. **Poultry manure:** It has been become popular consequent to the rapid growth of poultry industry. It is used for extensive cropping such as rice, sugarcane and chillies. The per cent nutrient composition of poultry manure is 0.9 N, 0.8 P and 0.5K.

Night soil: Human excrements both of solid and liquid material put together constitute Night soil. It is a rich source of N and P than cattle dung.

POUDRETTE

It is the product obtained from night soil without any admixture of other organic waste materials. Night soil is spread in thin layers over which copper sulphate and soil are lightly spread. The mass is periodically racked up and re-spread till dry. It is called poudrette. When it is properly prepared looks like a reddish loamy soil and in dry, powdery and devoid of offensive smell.

Night soil digestion: CPHERI (Central Public Health and Engineering Research Institute), Nagpur is working on night soil digestion, it provides

1. In offensive sludge with undiminished fertilizer value
2. Gas and electricity for rural areas

Night soil can be digested in a 230 sq .feet (6.5m3) digester without any fly or odour nuisance in an unheated open tank with manual stirring.

Design criteria for night soil digester

A. Capacity : 3-6 m^3
B. Raw night soil: water : 2:3
C. Gas yield : 3 m^3 /100 persons
D. Calorific value : 5558 K.Cal/ m^3 gas
E. Horse power generated for 100 persons : 2.0
F. Manurial value on dry basis (%) : 3-5 N, 2 to 4.4 P_2O_5 and 0.7 to 1.9 K_2O

The sludge in the night soil digester is removed in a week or two. The sludge can be spread on a drying bed of 3-5m^3 /100 persons where it can dry and be removed for use as manure.

The composition of gas (%): 65 CH_4, 34 CO_2 and 1 others on volume basis. Gas is used for running pump sets and street light lamps.

The supernatant liquid from the digester is mixed with garbage and compost and used as manure.

Sewage and Sludge

Sewage:

Sewage refers to the used up water from towns and cities collected though a drainage system. It consists of solid and liquid excreta and liquid wastes from kitchen and bath rooms. It also contains animal vegetable and mineral matter in suspension, solution and colloidal state. It is the mineral matter that makes the purification difficult.

Sewerage: Sewerage is the pipe system that carries the sewage for disposal

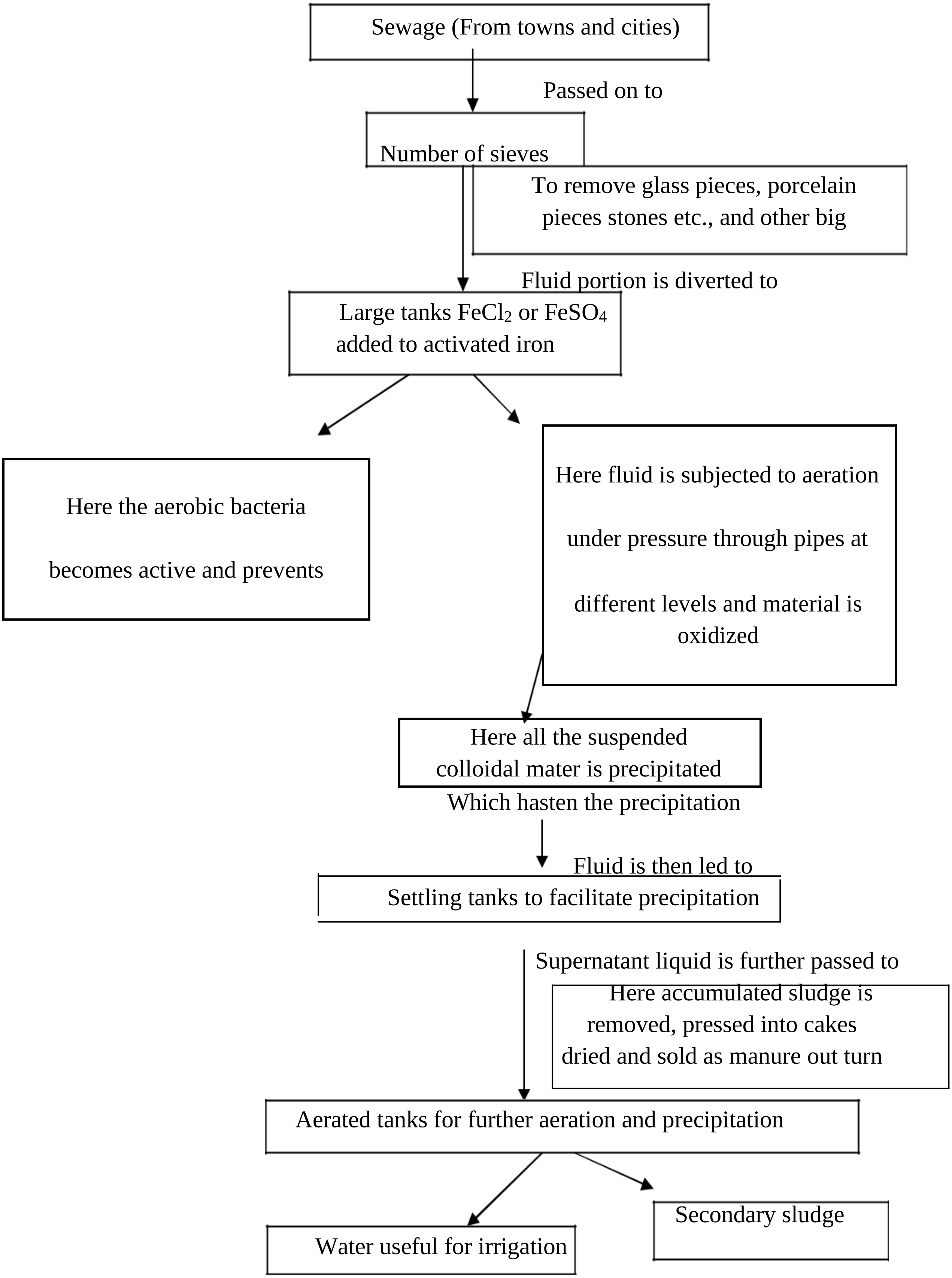
Sullage: Is the water drained from the kitchens, bathrooms and drainage water of the streets (open canal)

Effluent: It is the clear supernatant liquid obtained after aeration during sedimentation process in the septic tanks of the activated sludge process. It is fit for irrigation and rich in N.

Sludge: Sludge is he sediment that settles down in the activated sludge process .It is dark and powdery material with good manurial value.

Activated Sludge Process

In this process, the sewage is diverted outside the town or city and processed. There is specially constructed plant consisting of series of tanks fitted with pipes at different levels and the compressors to pump air under pressure. The following is a flow diagram for activated sludge process.



Out turn of the sludge is 15 per cent of entire sludge handled. Manurial value is 3.5% N-1.0% P_2O_5 - 0.5 to 1.0 % K_2O.

Advantages:

1. Maintain proper sanitary conditions
2. Large quantities of manure and water useful for irrigation
3. Generates good income to the local bodies
4. Avoids pollution of adjoining rivers and seas.

B. CONCENTRATED ORGANIC MANURES

I. Bone Meal:

Bone meal is a white to whitish material produced by treating the bones obtained in abattoirs (Slaughter houses). The bones are dried, crushed, degreased and cleaned to obtain bone grist. Finely ground, it serves as an organic N- P fertilizer.

Deamination: It is a process of removal of proteins from the grist which yields deaminated bone meal**.** It is also referred as steamed bone meal.

Bone meal is a P-fertilizer of organic origin i.e., it contains $Ca_3\ (PO_4)_2$. It has 1.0 to 2.0 per cent N and 10-13 per cent P .In general young bones contain less P and more nitrogen than older bones.

Bone meal has some residual effect. Rice and other cereals and other orchard crops respond well to its application. It is particularly useful for soils high in Fe and Al content and applied along green manures with advantage prior to sowing or planting. It can be used for crops rather indiscriminately without fear of salt damage (burning) unlike chemical fertilizers.

II. Horn Meal:

Horn powder, horn grist or horn chips can be obtained depending on the degree of crushing and collectively termed as horn meal. This is a slow acting fertilizer of Nitrogen containing 14 per cent N.

About 3-4 kg horn and hoof material can be obtained from each animal. Horn and hoof meal manufactured in India annually to the extent of 14,000 tones provided horns and hoofs of all the dead animals are collected and processed.

Horn and bone meal mixed fertilizers yield organic N-P depending on their composition (N from Horns and P from Bones).

III. Blood Meal/ Blood Powder:

Blood is collected from abattoirs (slaughter houses) dried and ground. Two types of dried blood are manufactured.

Red product: It is obtained by drying the blood with super heated steam and hot air.

Black product: It is obtained by evaporating the liquid blood over sand bath subjected to higher temperatures. It is evenly causes the loss of N and causes Charring.

Both red and black products are spread on the concrete floor covered with a net and allowed to sundry. This powder is used as manure.

Characteristics:

1) Blood meal absorbs moisture on exposure to atmosphere
2) Of all the protein organic manures, dried blood has the highest availability of N and given a rating of 80 (i.e.,) it is 80 per cent as efficient as the inorganic N fertilizer in providing the nitrogen to the crop.
3) An adult bovine (cow, buffalo /ox**)** gives 15 kg where as sheep or goat yields 1.5 kg of dried blood.
4) About 30-40 kg of dried blood is obtained from 100 kg fresh blood.
5) The principal component of blood is N .Which is 10-14 % in slow acting form.

IV. Meat Meal:

It is also referred as TANKAGE obtained from rejected carcasses (meat products) mostly meat and waste products such as leather scrap, feather, wool etc. These materials are cooked in steel tanks under pressure of 2 to 7 kg / cm^2 for 30-90 minutes. Addition of sulphuric acid (0.5%) facilitates hydrolysis at low temperature. It is dark brown and fluffy material. It contains 7 %N, 1 to 5 % P and 3 to 10 % K. Tank age has the rating of 60 per cent.

V. Fish Meal:

The non-edible fish, fish carcasses and offels (parts of butchered animal) are used to prepare fish meal .Such material are crushed or powdered after drying .The oil is generally removed before the meal is ground and facilitate easy decomposition .It is quick acting fertilizer suitable for all crops on all soils. It contains 7 to 8% N, 2 to 3 % P_2O_5 -and 0.2 to 0.5 % K_2O.

VI. Guano:

The name Guano is originated in PERU, from the word “HAUNO” to mean manure. GUANO is a product of sea bird (Pelican, Gannets, and Albatrosses) excrement covered over long periods and occurring in natural deposits. These birds live on islands with no rain or vegetation along with the pacific ocean coasts of PERU and CHILE and feed on abundant fish in the sea. These deposits may also have the excrements of turtles and seals together with the remains of dead bodies of birds ,bone, feather, sand and gravel etc., guano deposits are up to 60 meters thick ,however only central layer has a higher N-content . Guano has a colour varying from grey to dark brown, physical characters vary with the age, nature of deposit and amount of foreign material. It contains 8 to 15 % N and 2 to 3 % P. The chemical constituents are mainly ammonium oxalate and ammonium phosphate as well as calcium phosphates. There are important admixtures besides 2-4 % K.

Raw guano is some times processed into guano fertilizer by acid decomposition with sulphuric acid. This is called peru guano: 6+12+2 (N+ P_2O_5+ K_2O). Guano also occurs elsewhere as “cane fertilizer” produced by bats.

VII. Oil Cakes:

After removal of oil from seeds, the residue is made in to cakes. Oil cakes are used as organic fertilizers as they are rich source of organic nitrogen in protein form. In addition to N, small amounts of P, K and micronutrients. Oil cakes are classified into two groups viz.,

Edible oil cakes: Suitable for cattle and poultry feeding and also as a manure /fertilizer but not economical Eg. Groundnut, Gingelly cakes etc.,

Non –Edible oil cakes: Suitable for crop fertilization. Eg. Castor cake, neem cake etc.,

Edible oil cakes serve as fertilizers, but their use is restricted due to economic reasons .Composition of oil cakes are variable. Oil cakes are quick acting organic manures .The decomposability increases with decrease in oil content. They nitrify in about 30-45 days on addition to the soil. The rate of decomposition can be hastened by grinding the oil cakes into fine powder and thorough mixing with the soil.

1) Castor cake:

It is also called as castor pomace. It is the ground residue of beans from which oil has been extracted .it is poisonous to animals and used only as fertilizer. it is a by-product in the manufacture of castor oil. It contains 5 to 6 % N, 1 % P_2O_5 and 1.0 % K_2O . It has got a rating of 75 per cent.

2) Neem cake:

Neem cake is prepared by crushing the neem seed (with shells) in expellers and oil is separated. Neem tree is regarded as a “village dispensary” by virtue of its medicinal and antiseptic value. Neem cake is useful for cash crops mainly due to insect repellant or insecticidal properties owing to the presence of residual bitter and sulphur. Comparatively it contains higher N. It cannot be used as a cattle feed due to its bitter taste.

Chemical composition of neem cake

S.No.	Constituent	Content (%)
1	Organic matter	84.5
2	Moisture	9.9
3	Carbohydrates	17.5
4	Protein	36.2
5	Fiber	11.7
6	Oil	18.2
7	Ash	6.8
8	N	5.8
9	P	0.46
10	K	1.12

Neem cake has also been used as coating material over urea super granules as the former is reported to improve the fertilizer efficiency of soil applied urea.

Green Manuring

Green manuring can be defined as the growth of a crop for the specific purpose of incorporating it into soil while green, or soon after maturity with a view to improving the soil and benefiting subsequent crops or Practice of ploughing or turning in to the soil un decomposed green plant tissues for the purpose of improving physical condition as well as fertility of the soil.

Objectives of green manuring:

1. Increasing organic matter content of soil
2. Maintain and improve soil structure
3. Reduce the loss of nutrients, particularly nitrogen
4. Provide a source of nitrogen for the following crop
5. Reduce the soil loss by erosion

Types of green manuring:

The practice of green manuring is adopted in various ways in different states of India to suit soil and climatic conditions. Broadly speaking, the following two types of green manuring can be differentiated.

Classification of Green manuring: Classified into two groups as

I. Green manure *in situ*

II. Green leaf manuring

I. Green manuring *in situ*:

In this system, green manure crops are grown and buried in the same field which is to be green-manured, either as a pure crop or as intercrop with the main crop. This is most common green manure crops grown under this system are sunnhemp (***Crotalaria juncea***) ,daincha (***Sesabania aculeata***), Pillipesera (***Phaseolus trilobus***) and guar (***Cyamopsis tetragonoloba***).

The green manure crops are mostly legumes, which are fast growing and yield substantial succulent vegetation .There is little or no preparatory cultivation. Sowing is effected by broad cast adopting a heavy seed rate. Green manuring can be safely adopted for irrigated and irrigated dry crops viz., rice, sugarcane, tuber crops, vegetables and orchards. In case of dry crops it is unsafe because of limiting moisture. But when rains are sufficient and evenly distributed green manuring could be followed even under rain fed conditions when the rain fall is above 900 mm (Application of lime is suggested to neutralize organic acids that are formed during decomposition Bone meal preferred).

Green manure crops:

Sunnhemp (*Crotalaria juncea*):

1. It is a unique crop possessing, fiber, fodder and green manurial value with nutrient composition of 2.3 % N, 0.2 % P and 1.4 % K.
2. It can be raised beneficially for irrigated dry conditions
3. Under high rain fall conditions it is grown in dry lands
4. Grown in medium fertile soils
5. Seed rate is 45 kg ha^{-1}
6. Green matter yield 9-17 tonnes ha $^{-1}$

Daincha (*Sesbania aculeata*) and (*Sesbania speicosa*)

1. They are erect growing deep rooted crops and useful to open soil and improve drainage in heavy soils.
2. Nutrient composition (%) [3.5N,0.3P and 1.0K]
3. These crops are grown on heavy soils
4. They are non fodder crops and non palatable
5. They correct sodic soils specially *S. spaciosa* as it is less woody and less fibrous ,which gives heavy foliage and easily decomposable
6. Seed rate 30 kg ha $^{-1}$
7. Yield 5 tonnes ha $^{-1}$
8. Seeds require scarification for easy germination (Scarification means lightly pounding with sand).

Indigo (*Indigofera tinctoria*):

1. Slow growing, deep rooted drought resistant crop
2. It is not relished by cattle
3. Can be grown in fruit gardens and plantations during non –monsoon
4. Seed rate is 20 kg ha $^{-1}$
5. Yield is 5 tonnes ha $^{-1}$

Wild indigo (*Tephrosia purpurea*)

1. It is suited for hard coarse gravelly textured soil and poor soils.
2. It is used as a green leaf manure also
3. Self grown crop when sown once
4. Suitable for unirrigated orchards like mango, sapota
5. Nutrient composition (%) crop : 1.8N , 0.1 P and 0.3 K ; leaf : 3.2 N, 0.1 P and 1.2 K

Pillipesara (*Phaseolus trilobus*)

1. Regular green manure , minor pulse crop and fodder crop (triple purpose crop)
2. Popular green manure crop for black and alluvial soils
3. It has good ratooning capacity
4. The crop could be incorporated in to the soil after two cuttings for fodder
5. Yield : 3-5 tonnes ha^{-1}
6. Seed rate : 35 kg ha^{-1}
7. Chemical composition (%): 3 N,0.1 P and 0.3 K

Horse gram (*Dolichus biflorus*)

It is suitable as green manure crop for poor and hard soils. It can also with stands drought. Seed rate is 35 kg ha^{-1} and yield a green matter of 3.5tonnes ha^{-1}

II. Green leaf manuring:

Green leaf manuring refers to turning into the soil green leaves and tender twigs collected from shrubs and trees grown on bunds ,waste lands and near by forest areas. The common shrubs and trees used are Glyricidia, Sesbania speciosa, Karanj (Pongamia pinnata) etc.,

Plants used as a source of green leaf manure are as follows

Scientific name

Aeschynomene aspera

Azolla filiculoidea
Azolla pinnata
Calotropis gigantea
Cassia auriculata
Cassia siamea
Cyamopsis tetragonoloba
Ipomea carnea
Glyricidia maculate
Leucaena leucocephala
Pongamia glabra
Sesbania rostrata
Sesbania cannabina
Tephrosia purpurea
Tinctonia diversiflora

Advantages of green manuring (*in situ*):

1. Green manure crops can be chosen to suit the soil, season, water facility and cropping pattern
2. Reduces expenditure on collection and transportation of green leaf
3. It is easy to incorporate the green manure crop in right time
4. It reduces the loss of nitrogen from the soil

Limitations of green manure crops (*in situ*)

1. There must be sufficient time available for growing the green manure crop, nearly 2-3 months
2. Extra expenditure has to be incurred for growing green manure crop
3. Some of the green manure crops are of fodder value, they are liable for cattle tress pass
4. They are susceptible for pests and diseases as such they may harbour them as alternate hosts.
5. Need timely rainfall or irrigation etc., for growing
6. Seeds may not be available in time

Advantages of green leaf manuring:

1. All the quantity of green leaf applied is entirely an addition to soil –neither the moisture nor nutrients are utilized from the soil
2. There is no fear of spread of pests and diseases
3. It can be adopted at any time irrespective of the season

Limitations of green leaf manuring:

1. The green leaf is not available every where except in forest regions and waste lands
2. Green leaf which ever is available has to be used without choice
3. Green leaf may not be available sufficient quantity in all seasons
4. Extra expenditure on collection and transport has to be incurred

Criteria for green manure crop:

1. Capacity to fix atmospheric N in good amounts in symbiosis with micro organisms
2. Plethorcity of vegetative growth (heavy foliage)
3. Succulent vegetation with limited fibrous material
4. Deep root system to open the soil-for recycling of nutrients

5. Short duration with maximum and faster vegetative growth.

Advantages of leguminous crops:

Legumes have the capacity to fix nitrogen and generally decompose more easily than others. Legumes come up better in poor soils where non –leguminous may fail to put satisfactory growth.

Organic materials act as binding agents:

Organic materials acts as binding materials for holding soil particles as aggregates. There are there groups of binding agents as identified by TISDELL and OADES (1981)

1. Transient binding agents: These are plant and microbial products, rapidly decomposed, having more polysaccharides. They are produced by plant roots as mucigel or by bacteria as extra cellular components
2. Temporary binding agents: Fine plant root and fungal hyphae, mycorrhizal hyphae. They accumulate in soil over a period of time and persist for months or even years.
3. Persistent binding agents: Microbially resistant humic polymers derived from decomposition of plant residues, bacterial cells and fungal hyphae associated with Fe and Al in soils.

Chapter- 6

Soil organic matter – composition, decomposition, mineralization and immobilization

Substances containing carbon are organic matter. Soil organic matter consists of decomposing plant and animal residues. It also includes substances of organic origin either leaving or dead.

Soil organic matter plays an important role in deciding / maintaining soil physical conditions. It also influences soil chemical properties especially cation exchange capacity. Organic matters supply the energy sources for soil micro organisms. Soil development is another aspect which is influenced by the soil organic matter.

Plant tissue is the major source. Animals are considered as the secondary sources. They attack original plant tissues, contribute waste products and leave their own bodies after death.

Factors affecting soil organic matter

Climate
Natural vegetation
Texture
Drainage
Cropping and Tillage
Crop rotations, residues and plant nutrients.

1. Climate: Temperature and rainfall exert a dominant influence on the amounts of N and organic matter found in soils.

A. Temperature: The organic matter and N content of comparable soils tend to increase if one moves from warmer to cooler areas. The decomposition of organic matter is accelerated in warm climates as compared to cooler climates. For each 10°C decline in mean annual temperature, the total organic matter and N increases by two to three times.

B. Rainfall: There is an increase in organic matter with an increase in rainfall. Under comparable conditions, the N and organic matter increase as the effective moisture becomes greater.

2. Natural Vegetation: The total organic matter is higher in soils developed under grasslands than those under forests.

3. Texture: Fine textured soils are generally higher in organic matter than coarse textured soils.

4. Drainage: Poorly drained soils because of their high moisture content and relatively poor aeration are much higher in organic matter and N than well drained soils.

5. Cropping and Tillage: The cropped lands have much low N and organic matter than comparable virgin soils. Modern conservation tillage practices helps to maintain high OM levels as compared to conventional tillage.

6. Rotations, residues and plant nutrients: Crop rotations of cereals with legumes results in higher soil organic matter. Higher organic matter levels, preferably where a crop rotation is followed.

Composition of organic residues:

Plant residues contain 75% moisture and 25% dry matter. This 25% is made up of Carbon (10-12%), Oxygen (9-10%) , Hydrogen (1.5-2.5%) , N(1-2%) and mineral matter (1-3%).

Composition of plant tissues:

Carbohydrates
Celluloses -20-50%
Hemicellulose -10-30%
Starch, Sugar -1-5%
Proteins -1-15%
Fats, waxes, tannins- 1-10%
Lignins- 10-30%

Inorganic residues (mineral matter)
1. Water insolubles Soil organic residues

Nitrogenous	1. Proteins, Peptides Peptones and S containing materials 2. Water soluble (No_3, NH4 compounds)
Non Nitrogenous	Carbohydrates (celluloses Hemicellulose, ,Starch, Sugar etc) Ether solubles (Fats, oils, waxes, resins etc) Lignins

The organic matter is also classified on the basis of their rate of decomposition

1. Rapidly decomposed : Sugars, starches, proteins etc.
2. Less rapidly decomposed : Hemicelluloses, celluloses etc.
3. Very slowly decomposed : Fats, waxes, resins, lignins etc

Decomposition of soil organic matter:

Different organic residues contain different organic compounds. There is great variation in the rate of decomposition of organic residues. Sugars, starches and simple proteins are very rapidly decomposed. On the other hand Fats, waxes and lignins are very slowly decomposed. Hemicellulose, celluloses and protein are intermediate. Even though the composition may vary the end products are more or less the same. The general reactions taking place during decomposition are

Enzymatic oxidation of the bulk with the release of Co_2 , water, energy and heat
Essential elements are released (N, P, S etc) and immobilized by a series of reactions.
Formation of compounds which are resistant to microbial action.

Molecules very resistant to microbial action is formed either through modification of compounds or by microbial synthesis

Under aerobic conditions the products formed are

Co_2, NH_4, NO_3 , H_2PO_4, SO_4, H_2O and essential plant nutrients like Ca, Mg, Fe, Cu, Zn etc.

Under anaerobic conditions

CH_4, organic acids like lactic, propionic, butyric, NH_4, various amine residues ($R\text{-}NH_2$) H_2S, ethylene ($CH_2=CH_2$) and humic substances.

A. Decomposition of soluble substances: When glucose is decomposed under aerobic conditions the reaction is as under:

$$\text{Sugar + Oxygen} \rightarrow CO_2 + H_2O$$

Under partially oxidized conditions,

Sugar + Oxygen → Aliphatic acids (Acetic, formic *etc*.) or Hydroxy acids (Citric, lactic etc.) or Alcohols (ethyl alcohol etc.)

Under anaerobic conditions:

$C6H_{12}O_6$ (Glucose) - Lactic acid, butyric acid Ethyl alcohol are formed

B. Decomposition of Insoluble Substances

Breakdown of Protein: During the course of decomposition of plant materials, the proteins are first hydrolyzed to a number of intermediate products.

Aminization: The process of conversion of proteins to aminoacids.

Ammonification: The process of conversion of aminoacids and amides to ammonia.

ii) Breakdown of cellulose: The decomposition of the most abundant carbohydrates.

Hydrolysis, hydrolysis, oxidation

Cellulose → Cellobiose → Glucose→ Organic acids → $CO_2 + H_2O$

(cellulase) (cellobiase)

This reaction proceeds more slowly in acid soils than in neutral and alkaline soils. It is quite rapid in well aerated soils and comparatively slow in poorly aerated soils.

Breakdown of Hemicellulose:

Decompose faster than cellulose and are first hydrolyzed to their components sugars and uronic acids. Sugars are attacked by microbes and are converted to organic acids, alcohols, carbon dioxide and water. The uronic acids are broken down to pentose and CO_2. The newly synthesized hemicelluloses thus form a part of the humus.

Breakdown of Starch:

It is chemically a glucose polymer and is first hydrolyzed to maltose by the action of amylases. Maltose is next converted to glucose by maltase. The process is represented as under:

$$(C_6H_{10}O_5)n + nH_2O \rightarrow n\ (C_6H_{12}O_6)$$

C. Decomposition of ether soluble substances:

Fats □glycerol + fatty acids

Glycerol □CO_2 + water

D. Decomposition of lignin:

Lignin decomposes slowly, much slower than cellulose. Complete oxidation gives rise to CO_2 and H_2O.

Sulphur containing organic compounds:

Converted to SO_4^{-2} + H^+ + energy by sulphur oxidizing bacteria.

P containing organic compounds:

Various micro organisms mineralize phospholipids and other organic P compounds in the presence of phosphates enzymets H_2PO_4 and HPO_4^{-2} depending on soil P^H.

Mineralisation:

The biological conversion of organic forms of C, N, P and S to inorganic or mineral forms is called mineralization.

Immobilization:

The conversion of inorganic forms of C, N, P and S by the soil organism into organic forms is called Immobilization.

Factors affecting decomposition

Temperature:

Cold periods retard plant growth and organic matter decomposition. Warm summers may permit plant growth and humus accumulation.

Soil moisture:

Extremes of both arid and anaerobic conditions reduce plant growth and microbial decomposition. Near or slightly wetter than field capacity moisture conditions are most favorable for both processes.

3. Nutrients: Lack of nutrients particularly N slows decomposition.

4. Soil pH: Most of the microbes grow best at pH 6 to 8, but are severely inhibited below pH 4.5 and above pH 8.5.

1. Soil Texture: Soils higher in clays tend to retain larger amounts of humus.

2. Other Factors: Toxic levels of elements (Al, Mn, B, Se, Cl), excessive soluble salts, shade and organic phytotoxins in plant materials.

Role of organic matter

1. Organic matte creates a granular condition of soil which maintains favorable condition of aeration and permeability.
2. Water holding capacity of soil is increased and surface runoff, erosion etc., are reduced as there is good infiltration due to the addition of organic matter.

3. Surface mulching with coarse organic matter lowers wind erosion and lowers soil temperatures in the summer and keeps the soil warmer in winter.
4. Organic matter serves as a source of energy for the microbes and as a reservoir of nutrients that are essential for plant growth and also hormones, antibiotics.
5. Fresh Organic matter supplies food for earthworms, ants and rodents and makes soil P readily available in acid soils.
6. Organic acids released from decomposing organic matter help to reduce alkalinity in soils; organic acids along with released CO_2 dissolve minerals and make them more available.
7. Humus (a highly decomposed organic matter) provides a storehouse for the exchangeable and available cations.
8. It acts as a buffering agent which checks rapid chemical changes in pH and soil reaction.

Humus – Fractionation of organic matter –

Humus

Humus is a complex and rather resistant mixture of brown or dark brown amorphous and colloidal organic substance that results from microbial decomposition and synthesis and has chemical and physical properties of great significance to soils and plants.

Humus Formation

The humus compounds have resulted from two general types of biochemical reactions: Decomposition and Synthesis.

1. Decomposition:

a) Chemicals in the plant residues are broken down by soil microbes including lignin. b) Other simpler organic compounds that result from the breakdown take part immediately in the second of the humus-forming processes, biochemical synthesis. c) These simpler chemicals are metabolized into new compounds in the body tissue of soil microbes. d) The new compounds are subject to further modification and synthesis as the microbial tissue is subsequently attacked by other soil microbes.

2. Synthesis:

Involve such breakdown products of lignin as the phenols and quinones. a) These monomers undergo polymerization by which polyphenols and polyquinones are formed. b) These high molecular weight compounds interact with N-containing amino compounds and forms a significant component of resistant humus. c) Colloidal clays encourage formation of these polymers. d) Generally two groups of compounds that collectively make up humus, the humic group and the nonhumic group.

Soil organic matter fractions

1. Humic matter
2. Non humic matter

When soil is extracted with alkali the humic substances go into solution. The insoluble portion forms the non humic matter.

Humic group

1. This group makes up about 60-80% of the soil organic matter.
2. They are most complex. They are most resistant to microbial attack.
3. Humic substances have aromatic ring type structures.
4. These include polyphenols and poly quinones.

These are formed by decomposition, synthesis and polymerization. The humic substances are classified based on resistance to degradation and solubility in acids and alkalis into

1. Humic acid
2. Fulvic acid
3. Humin acid

Non humic group

1. This group makes upto 20-30% of the organic matter in soil.

2. These are less complex and less resistant to microbial attack as compared to humic substances.
3. They are polysaccharides, polymers having sugar like structures and polyurondes.
4. These include proteins, carbohydrates, lignins, fats, waxes, resins, tannins and some compounds of low molecular weight.

Theories on humus formation

Lignin theory: Proposed by Waksman (1936). According to this theory humic substances are formed due to the incomplete degradation of lignin

Kononovas theory: According to this theory humic substances are formed by cellulose decomposing mycobacteria earlier to lignin decomposition.

Polyphenol theory: (Flaig and Sochtig (1964)

1. As per this theory the humic substances are formed by the condensation of phenolic materials.
2. The polyphenols of lignin are oxidized to quinones.
3. These quinones are condensed with low molecular weight microbial products to form humic molecules.
4. The microbial products are amino acids, nucleic acid and phospholipids.

Properties of Humus

1. The tiny colloidal particles are composed of C,H, and O_2 .
2. The colloidal particles are negatively charged (-OH, -COOH or phenolic groups), has very high surface area, higher CEC (150 – 300 cmol/kg), 4 - 5 times higher WHC than that of silicate clays.
3. Humus has a very favorable effect on aggregate formation and stability.
4. Impart black colour to soils.
5. Cation exchange reactions are similar to those occurring with silicate clays

Clay – Humus Complex

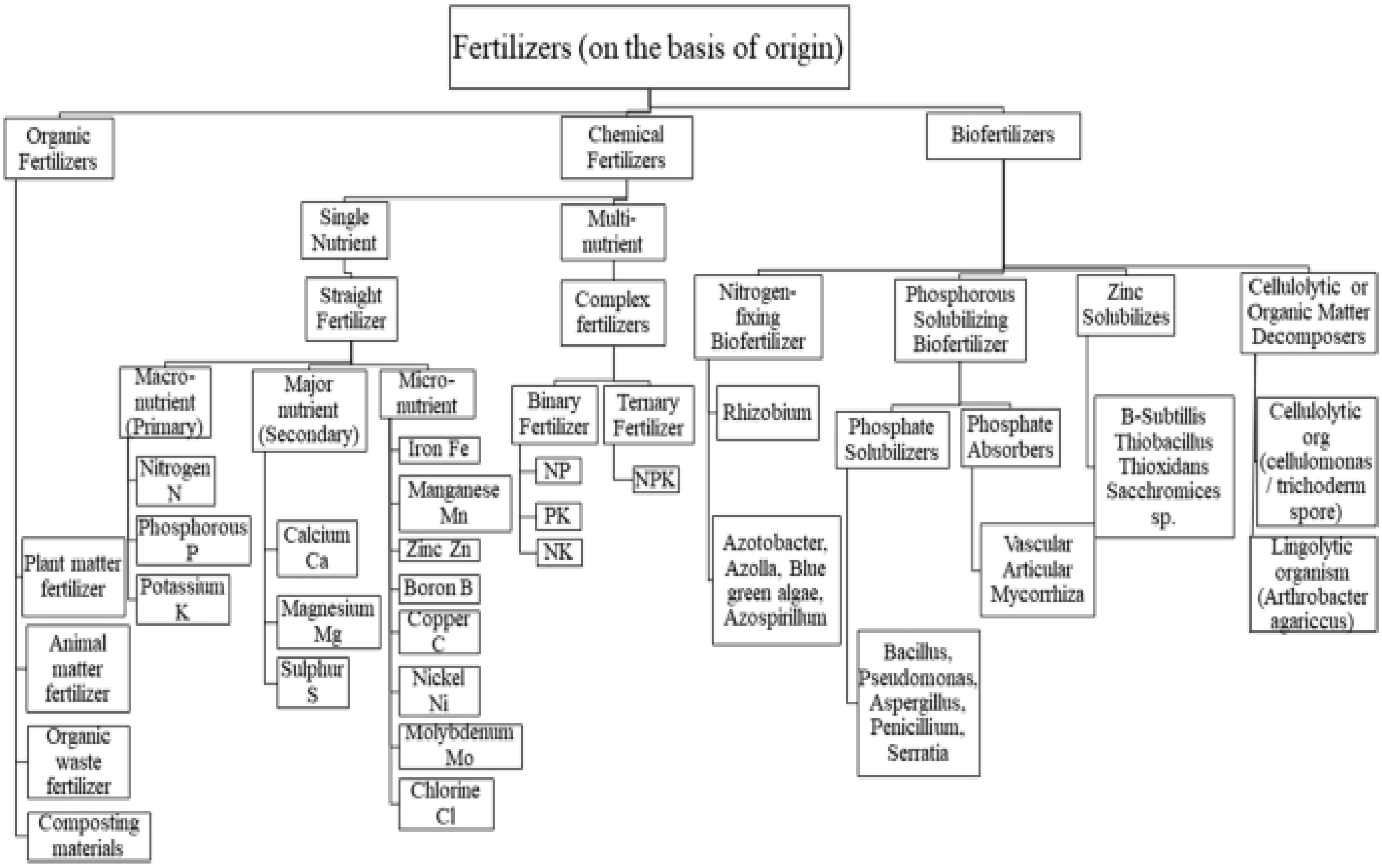
Humus, the organic amorphous colloid supplies both basic and acidic ions which is transitory and ultimately disappears from soil. Clay, the inorganic crystalline colloid supplies chiefly the basic nutrient ions is more or less stable. Both these colloids form the soil colloidal complex and are extremely active and form important sources of plant nutrients.

It is believed that humus and clay exist in the soil as clay – humus complex, the two being held together by cations like Ca, Fe, etc. Depending upon the nature of binding cation, two types of Clay – humus complex have been recognized. The colloidal complex bound by Ca ions is more stable and is responsible for the favorable physical condition of the soil, particularly its structure. The other type where Fe acts as the binding agent creates a poor physical condition of the soils.

Maintenance of Humus (Soil organic matter)

1. Maintenance of humus at a higher level is difficult.
2. This is due to the reason that the loss of carbon from the soil increases as the organic matter content is raised.
3. No attempt should be made to increase the organic matter content over that The soil plant-climate control mechanism can permit.
4. There is a strong linkage between soil Nitrogen and soil organic matter.
5. To maintain adequate level of organic matter in the soil the N level should be maintained by inclusion of legumes in crop rotation and judicious application of N fertilizers.
6. Loss of N from the soil is also to be minimized.
7. To maintain the organic matter level continuous addition of organic materials is essential.
8. These include animal manure, organic wastes and crop residues.
9. Incorporation of green manure will add to the organic carbon level of soil.
10. Ensuring vigorous crop growth by removing constraints in crop production will result in addition of root and top residues to the soil.
11. Conservation tillage (minimum tillage) should be followed to the extent possible.
12. This will reduce the decay of residues.
13. Keeping the land fallow to encourage natural vegetation is also advisable.

2. Classification of Fertilizers



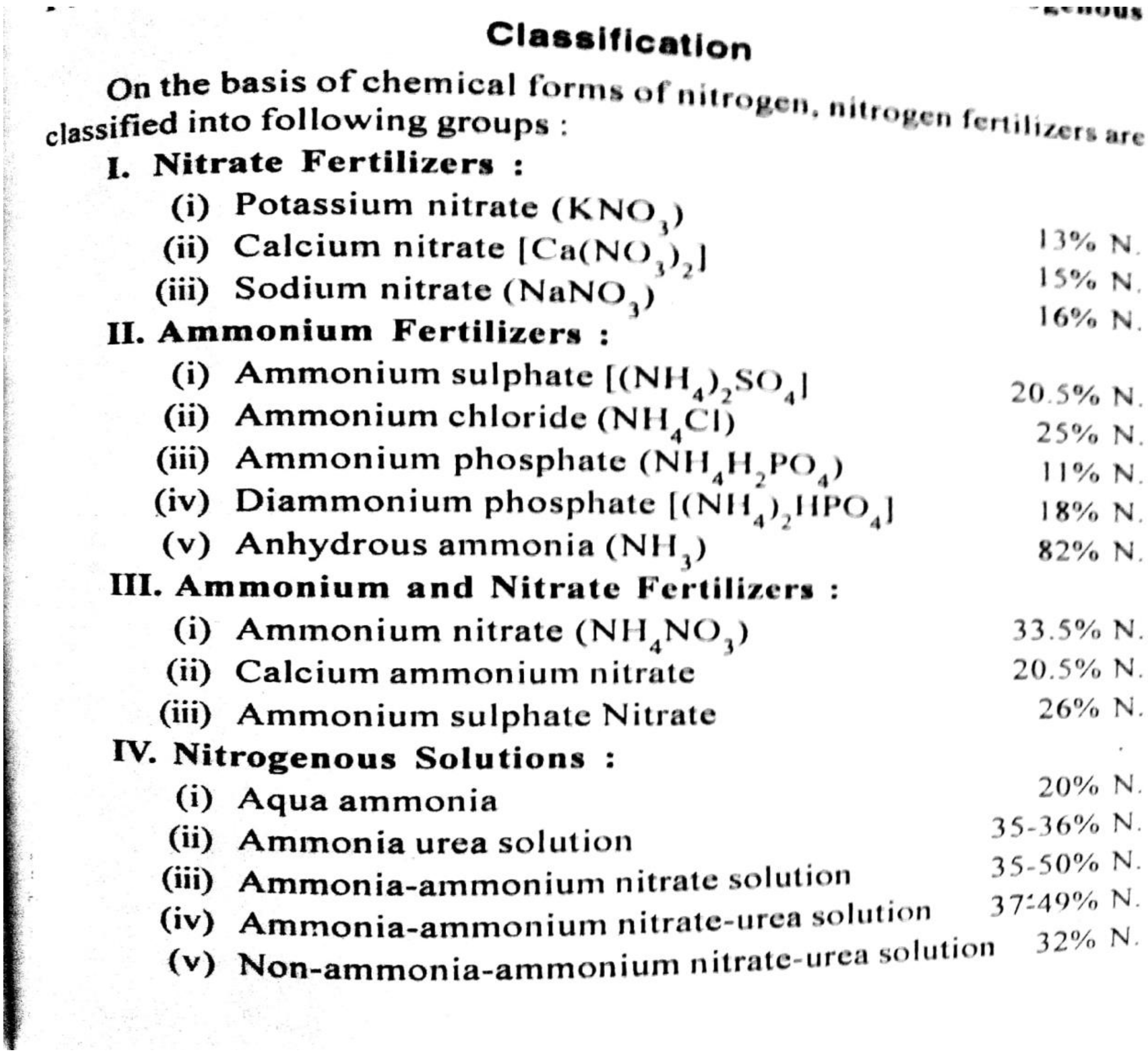
Nitrogenous fertilizers- Manufacturing process and properties of major nitrogenous fertilizers

A commercial fertilizer is defined as a material containing at least one of the primary nutrients in assemble or available form to plants in known amounts.

Nitrogenous Fertilizers

Nitrogenous fertilizers are chemical substances that contain the nutrient element nitrogen in absorbable form by plants chiefly as ammonium (NH_4^+) or nitrate (NO_3^-) or which yield these from after conversion.

Classification of nitrogen fertilizers



Classification

On the basis of chemical forms of nitrogen, nitrogen fertilizers are classified into following groups :

I. Nitrate Fertilizers :	
(i) Potassium nitrate (KNO_3)	13% N.
(ii) Calcium nitrate [$Ca(NO_3)_2$]	15% N.
(iii) Sodium nitrate ($NaNO_3$)	16% N.
II. Ammonium Fertilizers :	
(i) Ammonium sulphate [$(NH_4)_2SO_4$]	20.5% N.
(ii) Ammonium chloride (NH_4Cl)	25% N.
(iii) Ammonium phosphate ($NH_4H_2PO_4$)	11% N.
(iv) Diammonium phosphate [$(NH_4)_2HPO_4$]	18% N.
(v) Anhydrous ammonia (NH_3)	82% N.
III. Ammonium and Nitrate Fertilizers :	
(i) Ammonium nitrate (NH_4NO_3)	33.5% N.
(ii) Calcium ammonium nitrate	20.5% N.
(iii) Ammonium sulphate Nitrate	26% N.
IV. Nitrogenous Solutions :	
(i) Aqua ammonia	20% N.
(ii) Ammonia urea solution	35-36% N.
(iii) Ammonia-ammonium nitrate solution	35-50% N.
(iv) Ammonia-ammonium nitrate-urea solution	37-49% N.
(v) Non-ammonia-ammonium nitrate-urea solution	32% N.

Origin and reserves:

1) Nitrogen reserves on the earth are abundant. The earth's atmosphere consists of nearly 80 percent of nitrogen by volume.

2) Deposits of natural nitrates present in vast areas in CHILE and PERU of pacific coast of South America even up to 30 feet .The nitrogen containing salt of these deposits are called chile salt peter.

3) Bulk of the nitrogenous fertilizers are produced synthetically from atmospheric N via ammonia synthesis. Though plants are surrounded by atmospheric nitrogen (N_2). They can not split this highly stable molecule and convert it into utilizable forms under normal pressure and temperature conditions. But this splitting (splitting of N_2) can be done only by certain microorganisms in the presence of specific enzymes.

4) Production of N fertilizers from atmospheric nitrogen requires energy i.e., for producing 1 kg Nitrogen in the form of fertilizer it requires 40,000 Kilo Joules of energy.

Production of nitrogen fertilizers

Nitrogen fertilizers are produced by binding atmospheric nitrogen [N_2] by any one of the following process.

1. Ammonia synthesis by Haber –Bosch process
2. Calcium cyanamide synthesis
3. Nitrate synthesis by arc-gap process

Nitrogen fertilizers are produced essentially via ammonia synthesis with ammonia being further processed in to various nitrogenous fertilizers.

The other two processes could not economically compete with the Haber and Bosch process.

Manufacturing process:

Ammonia:

The production of ammonia (NH_3) a simple compound of hydrogen and nitrogen is the basis for nitrogen industry. The first full scale ammonia plant was established in 1913 by FRITZ HABER and CARP BOSCH at OPPAU, Germany for Badische, Anilin and SODA –FABRIC A.G (BASF). The process is called Haber –Bosch process.

In the Haber –Bosch process the reaction between molecular atmosphere nitrogen and hydrogen, the hydrogen is obtained by dissociation of water, or from natural gas etc., takes place at a pressure of 200 atmospheres and a temperature of 550 ^{0}C.

$$N_2\,(g) + 3H_2\,(g) \xrightarrow[550^0C]{200\text{ atm}} 2NH_3\,(g)$$

Synthesis of ammonia being an exothermic reaction produces heat so, that production of N_2 and H_2 requires large quantities of energy. As such production of ammonia is mainly a energy problem.

Raw materials:

Besides atmospheric air being the source of N_2, the other raw material used as a source for H_2 in the manufacture of ammonia include water, natural gas, naphtha, fuel oil or heavy petroleum fractions, coal and coke oven gas.

Water:

The electrolysis of water to generate H_2 requires an electric power of 4.40 to 6.00 K.W/m^3 of water. This method is adopted wherever abundant supply of electricity is available and cheep. Only one fertilizer plant at NFL (Nangal Fertilizer LTD.,), Bakranangal (Punjab) uses this process in India.

Natural gas:

The composition of natural gas varies with location. About 64 % of ammonia produced in the world is from natural gas. Natural gas is a mixture of gases viz., methane, ethane, butane, propane, pentane and CO_2 etc., of all these gases methane constitutes major portion varying 74 to 94 per cent by volume. Higher the concentration of methane lower will be C:H ratio requiring smaller purification unit.

Naphtha:

The light distillate fraction of petroleum with a maximum boiling point (B.P.) of 215 ^{0}C is called Naphtha, which is produced during the refining of crude oil .Naphtha contains hydrocarbons such as a) paraffin (79%) b) Olefins (1.0%) c) Naththanes (14 %) d) aromatics (6%). It has C:H ratio by weight around 5.48. About 75% of nitrogen produced in India utilizes NAPHTHA.

Fuel oil (or) Heavy petroleum products :

Fuel oil contains various products obtain from primary distillation and cracking of crude oil. Example: low sulphur heavy stock (LS HS) and heavy sulphur heavy stock (HS HS). Any of these fractions can be used to produce hydrogen gas.

Coal :

Coal contains hydrogen gas varying from 4.5 to 6.0 % by weight and carbon 79 to 85% by weight, besides sulphur to the extent of 0.3 to 6.0% depending on the location of this natural resources. Fertilizer plant at Ramagundam (Andhra Pradesh) is based on coal gasification to produce hydrogen.

Coke oven gas: Coke oven gas consists of gases (%) H_2 (52.6), CH_4 (28.9), CO (7.5) CO_2 (3.5) and produced during coal carbonization in steel industry.

Manufacturing process of Ammonia:

The process of ammonia synthesis involves four successive steps viz.,

1. Gasification
2. Conversion of CO to produce H_2
3. Gas purification
4. Synthesis

The first three steps are beyond the scope of the course.

Ammonia [or gaseous ammonia] :

Ammonia synthesis is carried out at elevated temperature of 550 ^{0}C and pressure of 200 atmospheres by passing N_2 and H_2 mixture (1:3 mole ratio) over an activated iron oxide catalyst. This process is carried out in a typical NH_3 synthesis reactor. It is a steel cylinder of 80-140 cm diameter and 10-18 meters height, provided with a catalyst container which helps for dissipating the heat expelled.

$$N_2 (g) + 3H_2 (g) \xrightarrow[550^0C]{200\text{ atm}} 2NH_3 (g)$$

(Over the activated catalyst)

Physical properties of ammonia:

1. Ammonia is a colour less gas with a pungent odour, when concentrated, it is toxic to humans and plants. But it is a plant nutrient and in dilute form is harmless to humans
2. One kg of ammonia contains 0.82 kg of nitrogen at 10 ^{0}C the gas exerts a pressure of 34.10 kg /inch ^{2} while the pressure at 38 0C is 89.50 kg / inch ^{2}. It is stored in steel or plastic tanks that can with stand the pressure of 120.4 kg / inch ^{2}.
3. Ammonia is handled on liquid under pressure and is released as a gas through an ammonia resistant hose into the soil. Copper and brass fittings reacts with ammonia and should not be used.
4. Ammonia contains 82 per cent nitrogen by weight.99.5 per cent nitrogen fertilizers are made from ammonia .It is the cheapest N-fertilizer to manufacture.
5. Ammonia is soluble in water up to 30% by weight .This gives a low pressure solution containing 24 per cent nitrogen called AQUA AMMONIA**.**
6. Ammonia is weak alkali. Ammonia and aqueous ammonia both being alkali (basic),the immediate effect of addition to soil is to raise the soil pH to above 9.0 in the zone of application .
7. Ammonia reacts with clay, organic matter and soil moisture. In warm aerated soil, microorganisms convert the applied ammonia to soluble nitrates after few days. The nitrate ions thus formed combine with Ca^{2+}, Mg^{2+} and K^+ and moves towards the growing root or percolating water. Thus, the final effect of ammonia is to reduce the basicity of the soil and to increase concurrently the soil acidity. One kg nitrogen applied as ammonia will require 1.8 kg of lime for neutralization.

Aqua ammonia [or aqueous ammonia] :

Manufacturing process:

It is the addition of anhydrous ammonia to water. The operation requires facilities for proportioning the flow of water and ammonia. Cooling is required to remove heat of absorption and measuring the concentration of aqua ammonia.

Physical and chemical properties of aqua ammonia:

1. Aqua ammonia is colour less solution with pungent odour, normally containing 20 % N. One liter of water can dissolve 700 liters of ammonia at 20 ^{0}C.
2. It is a non pressure solution which contains no free ammonia.

3. It can be handled and stored without the use of high pressure tanks and equipment.

Ammonia application to soil

The system consists of

1. Nursery tank
2. Ammonia application
3. Ammonia transferring system to till the applied from nursery tank and
4. Tractor to pull tank.
   - Ammonia is applied at 8” depth in the soil just below the tillage zone
   - Hot compressed NH_3 is stored in the nursery tank
   - Anhydrous NH_3 expands in the converts and doing so, it freezes, separating the liquid ammonia from vapour
   - The liquid ammonia flows due to gravity through hoses and gas in the soil.

Manufacturing process and properties of Ammonium sulphate, urea and CAN

(1) AMMONIUM SULPHATE [$(NH_4)_2$ SO_4]:

Introduction:

It is the oldest synthetic fertilizer. The production of Ammonium sulphate is related largely to the production of steel, a coke consuming process.

Manufacturing process:

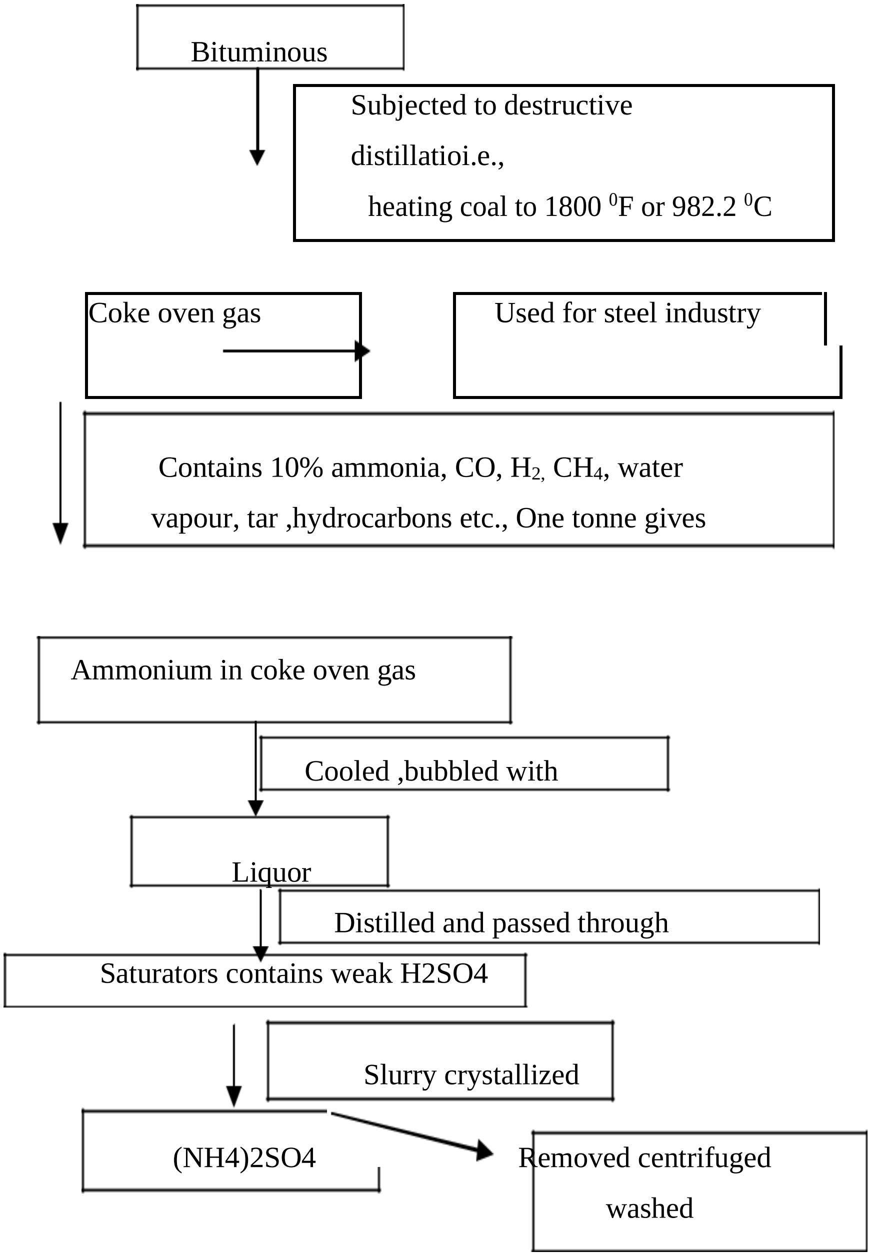
I. By product Process
II. Gypsum process
III. Neutralization process

By product process: [Raw materials Coal and Sulphuric acid]

In iron and steel production when bituminous coal is subjected to destructive distillation i.e., heating coal to 1800 ^{0}F (982.2 ^{0}C) in the absence of air, coke is obtained which is used for iron and steel industry. During this process coke oven gas is evolved which contains 10 per cent.

Ammonia by volume, besides the admixtures like CO, H_2 CH_4, water vapour finely divided tar particles and hydrocarbons etc., One tonne of coal burnt yields about 2-3 kg of ammonia. This coke oven gas is cooled and bubbled through water, when liquor ammonia is formed, which is distilled and passed into saturators containing weak H_2SO_4. Ammonium sulphate [$(NH_4)_2SO_4$] crystals are formed in the saturators are removed centrifuged, washed and drained. Reaction: $2NH_3$ (g) +H_2SO_4 → $(NH_4)_2$ SO_4 (salt) Energy 67.71K.cal/k.

Flow diagram



II. Neutralization process: [Raw materials NH_3 and H_2SO_4]

In this process, gaseous ammonia produced in **Haber and Bosch** process is directly neutralized with sulfuric acid to produce ammonium sulphate. The chemical reaction is exothermic.

Reaction: $2NH_3$ (g)+H_2SO_4(liquid) → $(NH_4)_2SO_4$ (salt) +67.710 k.cal /gram mole

Neutralization of ammonia by sulphuric acid takes place in reactor and the resultant slurry is transferred to crystallizer, where the heat of neutralization is advantageously utilized to evaporate the water in the slurry. Ammonium sulphate crystals are taken out from the bottom of the reactor and centrifuged. The crystal growth is regulated by air flow, time and temperature.

III. Gypsum process or leuna process: [Raw materials: NH_3 ,CO_2 and Gypsum)

In this process anhydrous ammonia is absorbed in water in a tank and CO_2 is pumped at 5 atmospheres. The resulting Ammonia carbonate is made to react with Gypsum (Calcium dihydarate; $CaSO_4$ $2H_2O$) suspended with water on double decomposition reaction, ammonia sulphate and calcium carbonate are formed. The calcium carbonate being insoluble, precipitated out, the ammonium sulphate solution is filtered out, and crystallized by evaporation.

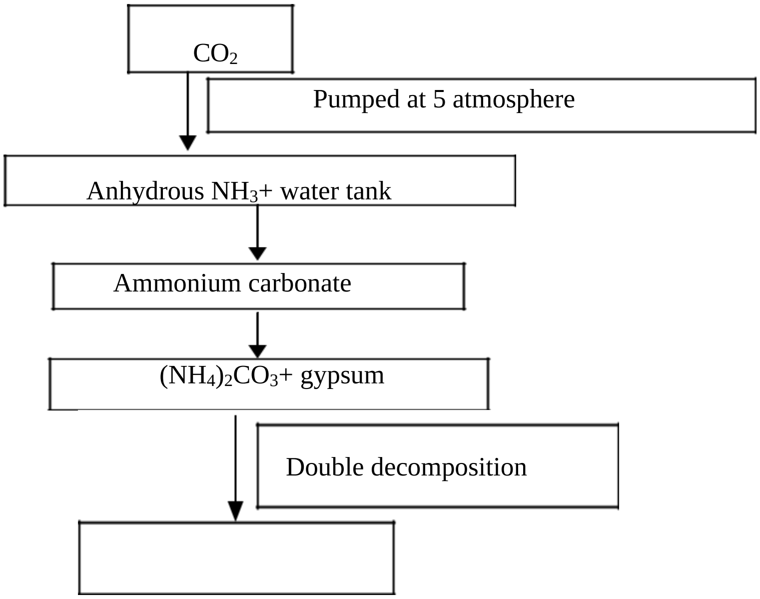
Reactions: $NH_3 + H_2O \leftrightharpoons NH_4OH$ + 8.32K.Cal/g.mole

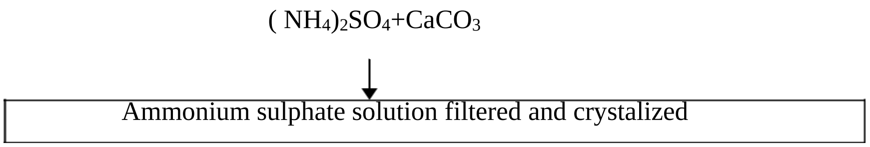
$2\ NH_4OH + CO_2 \rightarrow (NH_4)CO_3 + H_2O$ +22.08 K Cal /g.mole

$(NH_4)CO_3 + CaSO_4\ 2H_2O \leftrightharpoons (NH4)_2SO_4 + CaCO_3 + 2\ H_2O$+ 3.9K Cal/g.mole

Advantage of this process over other processes

1. In countries where sulphur supplies are meager and natural resources of gypsum are present ammonium sulphate can be produced without purchasing sulphur from abroad.
2. The by product $CaCO_3$ could be utilized for the manufacture of Calcium Ammonium Nitrate (CAN). Flow diagram





Physical properties:

1. It is white crystalline salt, but commercial product has light yellow to grey colour with free flowing character.
2. Thiocyanates when present are toxic to plants.
3. No problem in handling and storage ,if it contains some powdered material ,it cakes (stored in polythene bags)
4. Bulk density of $(NH_4)_2\ SO_4$ is 876.60 kg /m^3

Chemical properties:

1. Ammonium sulphate fertilizer contains 20.6 per cent N and 23.45per cent sulphur (It is a acid producing fertilizer)
2. Soluble in water at ordinary temperatures. Solubility at 0 ^{0}C is 70.60g/100 grams of water and at 100 ^{0}C is 103.80 grams /100 grams of water.

It has free acidity (pH =5.0) of 0.025 per cent by weight .One kg of N applied as Ammonium sulphate fertilizer required 5.1 kg of lime for neutralization.

(2) CALCIUM AMMONIUM NITRATE (CAN):

Calcium ammonium nitrate in one of the major straight N - fertilizer produced in India .It is also called as Lime Ammonium Nitrate.

Raw materials:

1) Ammonia 2) Nitric acid 3) Limestone or Dolomite 4) Soapstone (essentially magnesium silicate)

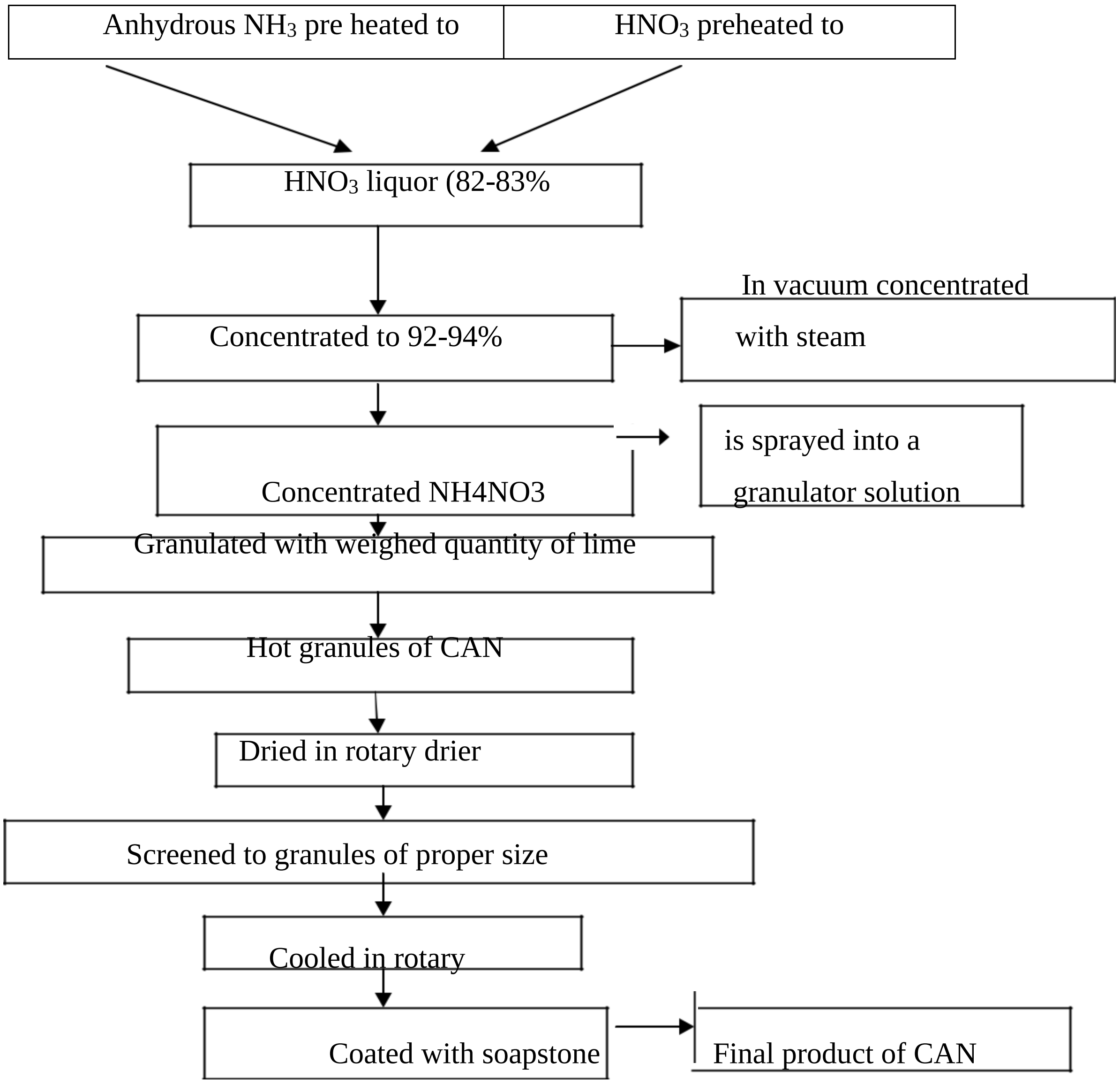
Manufacturing process:

Anhydrous ammonia and nitric acid are heated to 85 ^{0}C and 65 ^{0}C respectively by means of a steam vapour in a neutralizer, when ammonium nitrate liquor of 82 to 83 percent concentration is obtained .It is further concentrated to 92 to 94 per cent by heating with steam in a vacuum concentrator and stored in a tank.

NH_3 (g) +HNO_3 (liquid) → NH_4NO_3 (liquid) + 26 K.cal./g.mole The concentrated ammonium nitrate solution is(92-94 %) sprayed in a granulator fed with the weighed quantity of lime stone powder, when hot granules of Calcium ammonium nitrate are obtained .They are dried in a rotary drier by hot air and later screened to obtain the granules of proper size .They are cooled in a rotary cooler by air , and coated with soap stone dust (Talc) in a coating drum. The final product is a mixture of calcium carbonate and ammonium nitrate.

$NH_4NO_3 + Ca\ CO_3 \rightarrow NH_4NO_3\ CaCO_3$

Flow diagram:



Physical properties:

1. CAN is an easy flowing granular material (size 1 to 4 mm)

2. Addition of calcium carbonate (lime powder) during the manufacture of CAN improve handling character and reduced the explosive and hygroscopic nature of ammonium nitrate.

Chemical properties:

1. CAN contains 25 per cent nitrogen with equal quantity of each NH_4^+ and NO_3^- forms of nitrogen (12.5% and 12.5%)
2. It is a neutral fertilizer and leaves neither acidic nor basic residues on soil application
3. It contains 8.1per cent of calcium and 0.5per cent by weight of calcium nitrate
4. It is readily soluble in water

(3) UREA [Carbamide ($NH_2CO\ NH_2$)]:

Urea or carbamide as it is sometimes called "non-ionic" nitrogen compound used as a fertilizerfor crops and also as protein supplement in the feed of ruminants (farm animals).

1. It is the most important N-Fertilizer constituting nearly 91 per cent of the total production of nitrogen in India.
2. The major reason for its rapid growth is its very high nutrient content (46% N).

Raw materials: 1) Ammonia and 2. Carbon dioxide

Fwholer (German chemist), first prepared urea in the year 1828 [Commercial production started in 1922] by isomerizaiton of ammonia cyanate. Since then numerous processes have been developed for the synthesis of urea. All commercial processes are based on the dehydration of ammonia carbamate. The chemical reaction is follows.

$$2NH_3 + CO_2 \xrightarrow[2500\text{-}3500\ \text{Psi}]{180\text{-}200\ ^0C} \underset{\text{(Ammonium carbamate)}}{NH_4CO_2\ NH_2} \longrightarrow \underset{\text{(Urea)}}{NH_2\ CO\ NH_2} + H_2O$$

[Psi: Pressure in pounds per square inch]

Manufacturing process

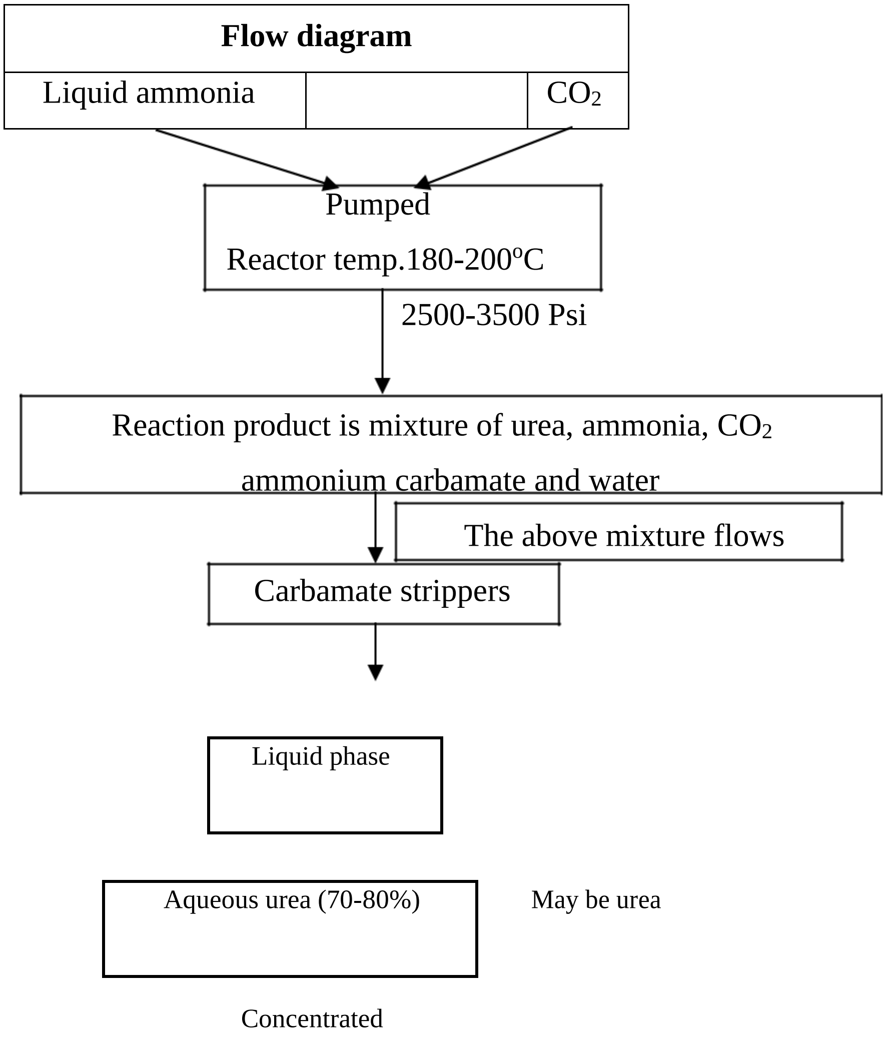
Liquid ammonia and carbon dioxide gas are pumped continuously into a reactor maintained at temperature ranging 180-200 ^0C and pressure ranging 2500 to 3500 Psi. The reaction is exothermic. The reaction product, is a mixture of urea, ammonia, carbon dioxide, ammonium carbamate and water. The mixture then flows in to a carbamate strippers, where liquid phase of urea, water containing small quantities of ammonium carbamate, ammonia and gaseous phase of ammonia, carbon dioxide and water vapour are separated. The aqueous urea solution contains around 70-80 per cent urea .It may be used directly in various nitrogen solutions, but must be concentrated to produce solid urea.

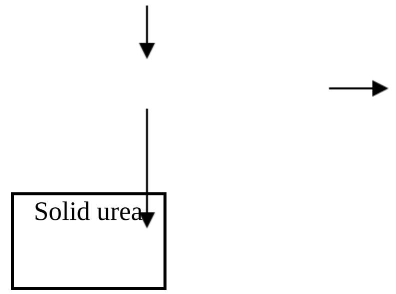
Biuret:

When concentrated urea solution is exposed to elevated temperatures i.e., greater than 100 ^{0}C during evaporation in prilling process biuret is formed by mixing of two urea molecules ,which is toxic to plants. At a temperature of above 100 0C

$$\underset{\text{Urea}}{NH2\ CO2\ NH2} + \underset{\text{Urea}}{NH2\ CO2\ NH2} \longrightarrow \underset{\text{Biuret}}{NH2\text{–}CO\text{-}NH\text{-}CO\text{-}NH2} + NH3$$

The urea solution concentrated to 99.70 to 99.80 percent in a vacuum evaporation and is finally dried by spraying in to a tower where it is solidifies in the form of prills (or) granules





Physical properties:

1. White organic compound with low bulk density i.e., 0.7 kg /L
2. It is a solid fertilizer usually granulated to (1 to 2 mm)
3. Having specific gravity of 1.335

Chemical properties:

1. Synthetic protein, organic compound, richest source of N (46%) in amide form among solid N fertilizers
2. Soluble in water and solubility is 100 g /100 g of water at 20^0C
3. Biuret content is about 1.5 per cent by weight
4. It is identical to urea found in animal urine.

What happens when urea is applied to soil

Conversion of urea in to ammoniacal and nitrate form is complete in about a week. As such it is advisable to apply urea three to four days before sowing of any field crop. Loss of nitrogen by leaching is less.

Urea is less acidic compared to ammonia sulphate. Since application of 100 kg urea leaves acidity, which requires 80 kg of $CaCO_3$ to neutralize it .Plants are capable of absorbing most of the nutrients through their leaves. Being very soluble and highly concentrated urea is most suitable fertilizer for spraying in the form of weak solution **(**3 to 6 %).

Urea is easily hydrolyses to ammonia soon after its application to the soil in the presence of urease enzyme by micro organisms and is converted to ammonium carbonate and then by microbial oxidation into ammonium and nitrate and these forms are absorbed by plant. Some of the ammonia and nitrate formed is lost due to leaching, volatilization and denitrification and these losses are responsible for the low recovery of urea by rice which is generally 40-50 per cent or even less.

$NH_2 CO NH_2 + 2H_2O$ $(NH_4)_2CO_3$

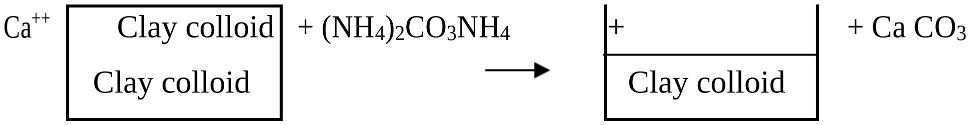
$(NH_4)_2CO_3 + 3O_2$ $2 HNO_2 + 3H_2O + CO_2$

$\rightleftharpoons$

$\rightleftharpoons$

$$2\,HNO_2 + O_2 \rightleftharpoons 2HNO_3$$

Urea being converted in to ammonium carbonate, the following reaction occur in the soil.



Calcium carbonate is in soluble in water and therefore its loss is minimum.

Urea is gaining importance as nitrogenous fertilizer because of the following reasons.

Urea was first produced in India at SINDHRI (BIHAR**)** during 1959-60. At present urea is producing nearly 50 different locations in India.

1. High nitrogen content 44 to 46 per cent
2. Good physical condition
3. Less cost per unit of nitrogen in production, storage and transportation
4. Less acidic residual effect as compared to ammonium sulphate
5. Suitable for foliar application
6. Lack of corrosiveness
7. Agronomic value equal to other nitrogenous fertilizers
8. The biuret content exceeds 1.5 %, it is toxic to plants.

Mode of action of N fertilizers in soils or reactions of fertilizers in soils

1. Urea (Refer fate of applied urea in soil)

2. Nitrate (NO_3^-) N fertilizers when applied to soil

1. Nitrate fertilizers raise the pH of the soil .These are superior in highly acid soil
2. Nitrate fertilizes are immediately effective and as such are specially suited for top dressing
3. These are also suitable for moderately to slightly acidic soils
4. Loss through leaching of Nitrate from soil are unavoidable but can be limited by precise N-fertilization

3. Ammoniacal N fertilizers [NH_4^+]

1. It is soil acidifier .It superior to neutral to very slightly alkaline soil.
2. Application of NH_4^+ Fertilizers to alkaline soils (pH =7.5) resulting in losses of gaseous ammonia .For this reason there are generally inferior in alkaline soils.
3. These are moderately quick in action. It becomes more mobile in the soil only after conversion to NO_3
4. Soil acidification through some N-fertilizers *viz*., Ammonium sulphate, urea ,brings about changes in soil reaction(pH). It is advantageous in soils with high pH, since contain trace elements are better mobilized through acidification.
5. NH_3 has fungicidal action against normal fungi in the soil.

4. Amide form (urea)

In general N fertilizers are very rapid in action in soils .Salt damage to crops occur due to heavy application of N fertilizers, which effects the absorption of water and mineral nutrients. Fertilizers can act effectively only when soil has optimum structure and soil reaction.

Phosphatic fertilizers –Manufacturing process and properties of SSP, TSP and Basic slag

Phosphatic Fertilizers

Phosphate fertilizers are chemical substances that contain the nutrient element phosphorus in the form of absorbable phosphate ions (anions) or that yield such phosphate anions after conversion.

Origin and reserves:

The raw material of P-fertilizers are essentially rock phosphates from phosphate deposits, phosphate ores and other P compounds. The deposits of phosphate rock exists in nature because of the low solubility of the compounds present. The composition of rock phosphates consists of various apatites (Calcium phosphate) which are partly as magmatic and partly as organogenic origin.

Magma: Weathering and decomposition of primary minerals

Organogenic: Bones,Teeth of animals, Guano deposits results in the formation of apatites.

Large deposits of rock phosphates occurs in

1. North Africa (Morocco, Algeria, Tunisia) in the form of organic crystalline phosphate, especially in a soft earth, finely crystalline form known as gafsa phosphates.
2. USA (eg. Florida apatite) in the form of pebbles.
3. USSR in the form of hard earth, coarsely crystalline kola apatite

In India phosphate rock deposits have been found in udaipur in Rajasthan and Mussoorie in Uttaranchal. Some deposits occur in Singbhum district (Bihar), Jhabhua district (M.P), Visakhapatnam district (AP), Tiruchanapalli (TN).

Production of phosphate fertilizers

Mineral P-fertilizers are obtained by chemical treatment or fine grinding of phosphates found in nature .Soft earth rock phosphates requires grinding where as hard earth raw material require chemical treatment. This is accompanied by-

1) Thermal methods
2) Chemical methods using H_2SO_4 or other acids
3) Combination of above two methods .[1 and 2 methods]

Classification of phosphatic fertilizers

Phosphatic fertilizers were classified by two ways. They are-

I. Classification of phosphatic fertilizers based on relative solubility of phosphate

II. Classification of phosphatic fertilizers based on the form in which orthophosphoric acid or phosphoric acid is combined with calcium.

I. Classification of phosphatic fertilizers based on relative solubility of phosphate:

Based on the relative solubility, the phosphatic fertilizers are classified into following three types-

1. Water soluble phosphorus fertilizers
2. Water insoluble but citrate soluble phosphorus fertilizers
3. Water and citrate insoluble phosphorus fertilizers

1. Water soluble phosphorus fertilizers:

Phosphorus in these fertilizers is present in water soluble form. P is present in the form of monocalcium phosphate $Ca\ (H_2PO_4)_2$. This form of P is generally regarded as the most readily available to plants.

1. Single super phosphate (16-18% P_2O_5)
2. Double super phosphate (32 % P_2O_5)
3. Triple super phosphate (46-48% P_2O_5)
4. Higher content or concentrated super phosphate
5. Ammonium phosphate (20% N and 20% P_2O_5)

These fertilizers are suitable for neutral to alkaline soils and should be applied at the time of sowing. Immediately after application, phosphorus gets converted into insoluble dicalcium phosphate. Hence the P fertilizers containing water soluble P should be applied in granulated form rather than powdered form. Contact between soil and fertilizers should be reduced. Hence pocketing of fertilizers is beneficial than broad casting. Under acidic conditions, water soluble phosphoric acid gets converted into unavailable iron aluminium phosphates.

2. Water insoluble but citrate soluble phosphorus fertilizers:

Phosphorus present in these fertilizers is soluble in 2% citric acid or neutral normal ammonium acetate solution. P is present as dicalcium phosphate $Ca_2H_2(PO_4)_2$ / $CaHPO_4$.

1. Basic slag (14 to 18% P_2O_5)
2. Dicalcium phosphate (34-39 % P_2O_5)

3. Raw and steamed bone meal (part of the P_2O_5 soluble in citric acid) – suitable for acid soils and lateritic soils.

The fertilizers of this group are particularly suitable for the acidic soils, because with low pH citrate soluble phosphoric acid gets converted into monocalcium phosphate or water soluble phosphate, and there is less chances of phosphate getting fixed as iron and aluminium phosphate. Contact between soil and fertilizer should be more to solubilize the citrate soluble P present in the fertilizer. Hence they should be applied as broad casting to increase contact with soil.

3. Water and citrate insoluble phosphorus fertilizers:

Phosphorus present in the fertilizer is not soluble both in water and citrate solution containing insoluble phosphoric acid or tri calcium Phosphate $(Ca_3(PO_4)_2$.

1. Rock phosphate (20 to 40 % P_2O_5)
2. Raw bone meal (20 to 25% P_2O_5)
3. Steamed bone meal (22% P_2O_5)

These fertilizers very well suited for acidic soils or organic soils, which require large quantities of phosphatic fertilizers to raise the soil fertility. They should be applied as broad casting to facilitate intimate contact with soil. They should be applied one month before taking up the crop so that insoluble-P gets solubilized by the time of sowing of crop.

II. Classification of phosphatic fertilizers based on the form in which orthophosphoric acid or phosphoric acid is combined with calcium.

The phosphatic fertilizers can be classified broadly into three groups, depending on the form in which orthophosphoric acid or phosphoric acid is combined with calcium. They are:

1. Ortho phosphates Eg. MAP, DAP, UAP, SSP, Nitro phosphates
2. Polyphosphates Eg. Ammonium poly phosphate, Potassium poly phosphate
3. Metaphosphates Eg. Ammonium meta phosphate, Potassium meta phosphate

Available Phosphorus: The sum of the water soluble and citrate soluble values is taken as an estimate of the fraction of the total P which is available to plants.

Total phosphorus: The total P is the sum of the available and citrate insoluble fractions. It is determined by treating a sample of the original material with strong acids and analyzing the solution for phosphates.

Manufacturing processes:

1. Ground rock phosphate
2. Single super phosphate
3. Triple super phosphate
4. Basic slag.

I. Ground Rock Phosphate:

The World phosphate industry is based essentially on deposits of rock phosphate – a fluoride bearing complex of calcium phosphates. The content of rock is usually expressed in terms of its tricalcium phosphate [$Ca_3(PO_4)_2$] equivalent.

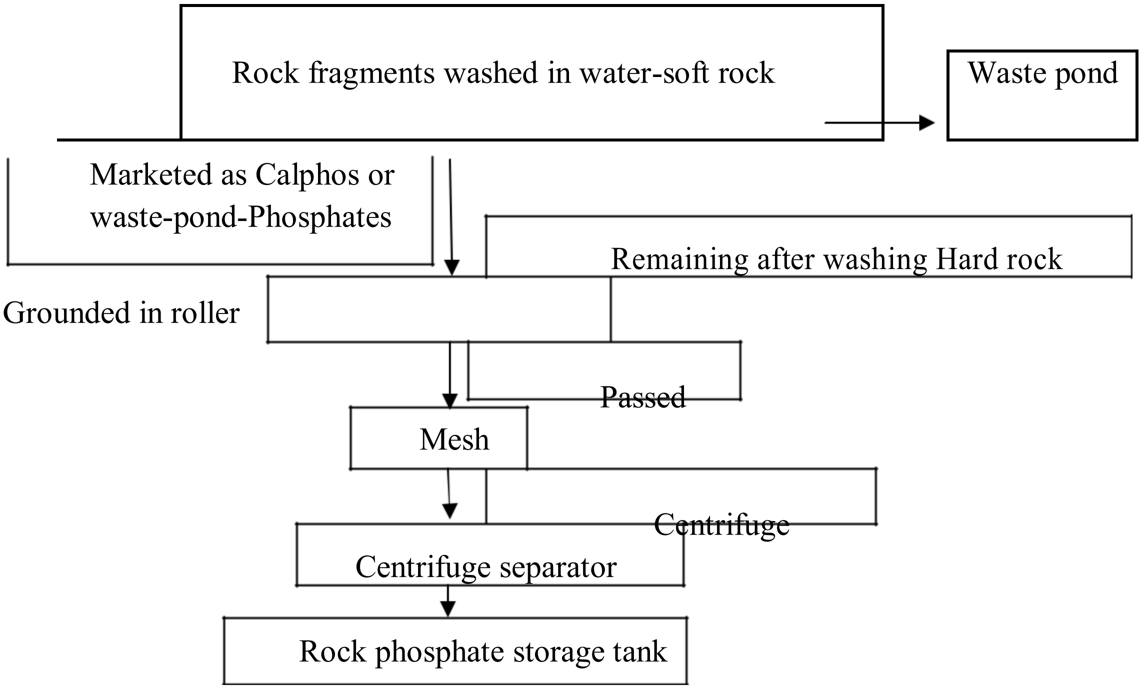
Four kinds of rock phosphate are recognized viz., 1) soft rock phosphate. 2) Hard rock phosphate (Hard earth). 3) Land pebble phosphate. 4) River pebble phosphate.

The exposed rock phosphates are washed with water into the waste ponds, where soft rock phosphates (soft earth) settle out with clay and other impurities. The fractions remaining after washing i.e., hard phosphate rock, land pebble phosphate are ground to pass to through 0.14 mm sieve (100 mesh screen) either in a roller mill or ball mill and the resultant rock phosphate powder is carried out a centrifugal separator by means of an air blower. The product is discharged into a storage tank. The plant (industry) can grind about 50 tonnes of phosphate rock per hour. Previously waste ponds containing soft phosphates and clay material is marketed under trade names in USA viz., Colloidal phosphates, mineral colloids, Calphos and phos-cal-oids. These products are known in the fertilizer industry as waste-pond phosphates.

Physical and chemical properties:

1. The fine powder of phosphate rock is known as float to mean un acidulated ground rock phosphate
2. The mineral in phosphate rock is apatite which has the general formula **[$Ca_{10} (PO_4)_6$ (F, Cl $(OH)_2$ ($CO_3)_2$]**
3. Contain about 10-16 % P and varying amounts of lime (7-10% Ca CO_3) and, silica fluoride [3-4% F] iron and aluminum as impurities.
4. It has no practically water soluble phosphates (10^{-7} molar P), but less than 30% of P is soluble in 2.0% citric acid solution.
5. Waste pond phosphates contain 7-9 % P out of which 1 to 2 % phosphate rock is soluble in 1 N neutral ammonium acetate.

FLOW DIAGRAM



Action of rock phosphate on acid soils:

When finely ground rock phosphate is applied to acidic soils or to soils containing high percentage of organic matter, Carbonic and nitric acids present in the soil act on rock phosphate, which is containing tricalcium(unavailable) and convert unavailable phosphate to mono calcium phosphate or water soluble phosphate which is easily available to growing plants. It has been observed reactions in the following manner.

$$[Ca_3(PO_4)_2]_3 + 6\ H_2CO_3 \rightarrow 3\ Ca(H_2PO_4)_2 + 7CaCO_3$$

[Rock Phosphate [Carbonic acid] → [Mono calcium phosphate]
Containing no fluoride] [Available]

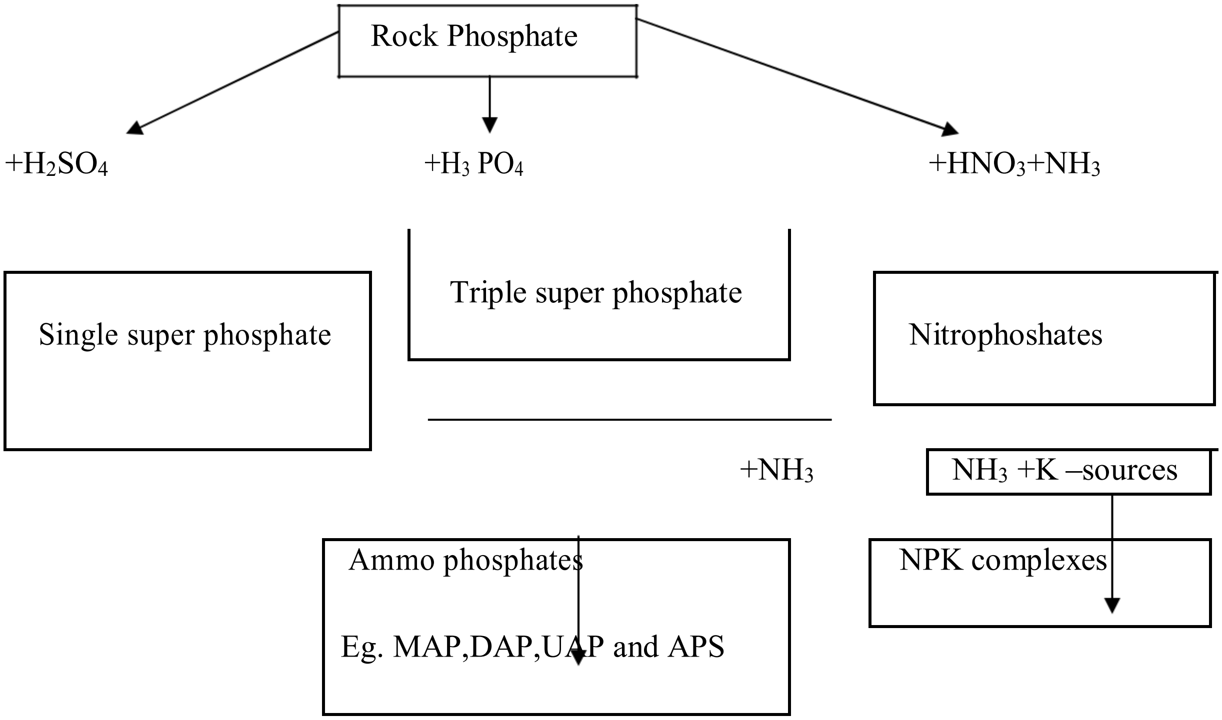
$$Ca_3(PO_4)_3\ CaCO_3 + 14\ HNO_3 \rightarrow 3\ Ca(H_2PO_4)_2 + 7Ca(NO_3)_2 + H_2CO_3$$

In general ground rock phosphate should be applied in large quantities of 500 to1000 kg per hectare once in three years, but should not be applied in small quantities every year. It should be thoroughly mixed in the top soil with country plough or disc harrow.

Strongly acidic soils are most suitable for direct application of rock phosphates. Such areas are found in whole Kerala, Shimoga, Mysore, parts of Assam, Bihar, Mussorie rock phosphate and Purulia rock phosphate have been recognized by ICAR for direct application.

Direct uses of rock phosphate [R.P.]

1. Around 90% of rock phosphate is used in the manufacturing of phosphatic fertilizers:



2. Direct use of Rock Phosphate [R.P] is mainly for acid soils. Acidic soils contain acids which react with rock phosphate yield monocalcium phosphate (MCP), which is available to plants.

Use of Rock phosphate as direct application depends on the following factors:

1. **Soil reaction**: Not applied in neutral and alkaline soils
2. **Dose and time of application:** It should be applied in large quantities once in 5-6 years, it should be finely ground
3. **Plant Species:** R.P. is useful for calcium loving plants like legumes .It should be applied for long duration commercial crops.
4. **Soil organic matter:** Can be applied in soils containing higher amounts of organic matter because acids are produced during decomposition, then the tricalcium phosphate (TCP) is converted to mono calcium phosphate (MCP).
5. **Organic manures:** R.P. can be applied along with undecomposed organic materials like green manures because during decomposition acids are secreted.

6. **Phosphocompost:** Applying rock phosphates along with phosphorus solubulizing bacteria with or without sulphur and sulphur oxidizing bacteria. During the decomposition process of plant and animal sources (residues) is called phosphor compost. Acids produced during composting convert TCP to MCP.
7. **Phosphate solubulizing bacteria:** When RP is applied to neutral soils, it is applied with phosphorus solubulizing bacteria.
8. **Fertilizers:** It can be applied along with acid producing fertilizers. It is also applied along with the SSP, because MCP produces H_3PO_4 which in turn converts TCP in R.P. to MCP.
9. **Biosuper:** Super phosphate produced by biological organisms. Application of R.P. along with sulphur or without sulphur oxidizing bacteria.

$$S+2O_2 \longrightarrow SO_4^{-2}$$

$$SO_4^{-2}+H_2O \longrightarrow H_2SO_4$$

In this process sulphur get oxidized to sulphate and which, forms H_2SO_4**,** which will be helpful in acidulation of Rock phosphate. Phosphate fertilizers are those fertilizers which contain PO_4 ion in plant absorbable form or which yield on conversion.

II. SINGLE SUPER PHOSPHATE [16% P]:

Super phosphate is a term used in reference to phosphates of which is in a form readily available to plants.

Single super phosphate is the oldest artificially produced fertilizer and its manufacture dates back to 1842, when **LAWES J.B** prepared for the first time in ENGLAND by treating Rock phosphate with sulphuric acid.

Manufacture process of single super phosphate

Raw materials:

1) Phosphate rock.
2) Sulphuric acid.

Single super phosphate is (SSP) is manufactured by mixing gravimetrically equal parts of sulphuric acid (75%) and rock phosphate of 0.14 mm [100 mesh seive] There are two methods of preparation of SSP viz**.,**

1. Den process

2. Continuous rock phosphate acidulation process

1. Den process:

Weighed quantities of Rock phosphate (0.14mm) and sulphuric acid (75%) are mixed in a mixer**,** capable of handling40-50 tonnes per hour, are allowed to react for about a minute and the resultant slurry is dumped in to a compartment known as DEN [100-300 tonnes capacity]. In a few hours the reaction goes to completion. Water, carbon dioxide, fluorine, volatilize away resulting in the reduction in the bulk of the material by retaining the material in the Den becomes a hard block and removal is accomplished by means of mechanical excavators equipped with revolving knifes which cut into the block and the disintegrated SSP is stored for 2 to 6 weeks to cure and attain the desired physical condition.

2. Continuous rock acidulation process:

This is a popular and latest process in which acidulation of rock phosphate with sulphuric acid is done continuously in mixer provided with indigenous metering (H_2SO_4) and weighing (RP) devices. The mixer is agitated for 2-3 minutes and is then discharged into an endless conveyer belt on which it solidifies. The belt conveyer moves the blocks of hardened super phosphate towards a revolving cutter which disintegrate the material. It is then transferred to a storage bin and stored for 2-6 weeks to cure and attain the desired physical condition.

The chemical reaction (Exothermic) involved in both processes are same as represented below

$Ca_{10}[PO_4]_6F_2 + 7H_2SO_4 + 3H\ O \longrightarrow 3CaH_4(PO_4)_2H_2O + 7CaSO_4 + 2HF$ [Super phosphate i.e.,Monocalcium phosphate]

Three points are suggestive of the above equation viz.,

1. Phosphate originally present as apatite is converted into water soluble Monocalcium phosphate.
2. The by-product reaction is gypsum which is initially mixed with the monocalcium phosphate.
3. The reaction releases toxic hydro fluoric acid gas.

Physical properties of SSP:

1. SSP is in granular form has bilk density 961.10 kg m^{-3} and is easy to handle.
2. SSP is also available in powder form, it is not free flowing and being slightly hygroscopic has a tendency to cake. Hydration of monocalcium phosphate may be the cause for hardening SSP. It has grey colour and an acidic odour.

3. Free acid in the SSP, will usually rot the jute fibre bags and hence the fertilizer has to be stored in polythene lined gunny bags or polyethylene bags.

Chemical properties of SSP:

1. SSP has 2/5 Mono calcium phosphate and 3/5 Gypsum by weight.
2. SSP manufactured in India consists of two grades viz., Garde I: 16% P_2O_5 % or (7%P) by weight of water soluble P_2O_5 and Grade II: 14% P_2O_5 or (6%P) by weight of water soluble P_2O_5 .
3. SSP also contains 21.0% calcium, 12% sulphur and traces of micronutrients .Obviously it contains more sulphur (12%) than phosphorus (6 to 7%).
4. SSP has a pH of about 3.0.

3. TRIPLE SUPER PHOSPHATE (46 % P_2O_5):

Its high plant nutrient content and its capacity to react with NH_3 in the production of multinutrient fertilizers. The 'prefix' 'TRIPLE' was first used when SSP contained 16 % P_2O_5 and TSP contained three times as much as 48% P_2O_5 .

Manufacturing process:

Raw materials:

1. Rock phosphate.
2. Phosphoric acid.

TSP is obtained by acidulating finely ground phosphate rock (0.14 mm) with phosphoric acid.

$Ca_{10}[PO_4]_6F_2 + 14\,H_3PO_4 + 10H_2O \rightarrow 10\,CaH_4(PO_4)_2H_2O + 2HF$

The method of manufacture is called CONE MIXER PROCESS.

The phosphate rock (100 mesh) is mixed with phosphoric acid (75%) in a cone mixer in the acid –rock ratio (expressed as eh mole ratio of total P_2O_5 to CaO in the acidulate) of 0.91 to 0.95.The resultant slurry is then fed to a belt conveyer [as already described in case of SSP. An extended curing period of about 30 days is required for the reaction to complete, for attaining described physical condition].

Physical properties of TSP:

1. TSP in powdery form is not free flowing, has a tendency to form lumps on storage. However, the granulated product has excellent handling and storage characters and is free flowing.
2. It has bulk density 800-881 kg m^{-3}
3. TSP is to be packed in polyethylene lined jute bags or multi wall paper bags to prevent rotting due to free phosphoric acid.

Chemical properties of TSP:

1. The main phosphate compound present in TSP is monocalcium sulphate.
2. It contains 46% total P_2O_5 by weight and 36.8% minimum by weight of water soluble P_2O_5.
3. It has 3% free phosphoric acid.
4. TSP also contains 12 to 16% of calcium and 1.0 to 2.0 % of sulphur.

4. BASIC SLAG [$(CaO)_5$ P_2O_5 SiO_2]:

Basic slag is a by product of steel industry. It also called as "Thomas slag" named after the inventor of the production process, the English metallurgist, **THOMAS (1877).** Millions of tonnes of "slag" have been used as a source of P in European Agriculture.

Manufacturing process:

Iron ores contains several impurities and phosphorus is one. Elimination of phosphorus is essential for obtaining high quality steel. Steel with over 2 % P is brittle.

Basic slag or Thomas slag is produced by open - hearth process. In this process, the iron ore and lime are heated by means of producer gas in a open hearth. Fluorospar a mineral [Natural calcium fluoride] is added at the rate of 3.4 kg per tonne of lime to reduce viscosity of the slag. When the mixer becomes red hot, the lime melts and unites with acid impurities including phosphoric acid. The resulting compounds containing Ca, P, Si , Mg and Mn are lighter than iron ore and as such raise to the surface of the molten mass and are poured off as slag. After the slag is cooled, become hard massive block. It is crushed and ground to a fine powder.

Physical properties of slag:

1. Heavy, dark brown powder, ground and pass through 100 mesh sieve.
2. Has relatively higher density than any other fertilizer material.
3. It is likely to solidify when exposed to moisture.

Chemical properties of phosphatic fertilizers:

1. The basic slag is a double silicate of phosphate and lime
2. The slag obtained from Indian steel industry contain only 3-8 % P_2O_5. Being low in P_2O_5 having highest viscosity, it is not popularly used in Indian agriculture.
3. Being low in P_2O_5 it is currently enriched with rock phosphate and marketed as pelophos which on analysis contains 11.0 % citrate soluble and 5.0% water soluble P_2O_5
4. It is alkaline in reaction and has neutralizing effect equal to 70% $CaCO_3$ equivalent.

Mode of action of P fertilizers in soils or reactions of fertilizers in soils

1. Water soluble P-fertilizers lead to better P-absorption in the neutral soils, whereas water insoluble P fertilizers are often superior in acid soils.
2. Fertilizers like SSP improves the soil structure because of its gypsum component. It also have a slight soil acidifying action.

Potassic fertilizers –Manufacturing process and properties of Muriate of Potash and sulphate of potash

Potassic Fertilizers:

The Latin / German word for the element with symbol K is" **Kalium**". It is derived from the Arab word **"el-kali"** means **ash (Potash in English, Potassic in French).**

The term potash generally refers to any salt used to provide fertilizer potassium. In early days, potassium carbonate was produced from solutions leached form wood ashes evaporated in iron pots, hence term potash meaning "pot ashes".

The crude potassium salts (K-minerals with impurities) were found in the processes of drying up of sea water in former ocean basins which occur largely during the permian period some 200 million years ago .The sea water salts crystallized in the order of solubility i.e., (common salt) NaCl, strata are overlain by K-minerals. In course of time they were covered by many geological strata and converted to a hard rock. Crude potassium salts are thus natural sea water minerals.

Potassium content of earth crust is 2.40 %, whereas the content of phoshorus is only 0.11%. Potassium reserves are large. The large deposits of potassium salts are in North America (Canada, USA), USSR, West Germany, East Germany and France in that order. The important potash minerals of the world occurring as deposits and their chemical composition are given

Principal potash minerals of the world

S.NO.	Mineral	Chemical formula	Approx. Content of K (%)
1	Carnallite	$KCl\ MgCl_2\ 6H_2O$	14.1
2	Kainite	$KCl\ Mg\ SO_4\ 3H_2O$	15.7
3	Langbeinite	$K_2SO_4\ 2\ Mg\ SO_4$	18.8
4	Nitre	KNO_3	38.6
5	Polyhalite	$K_2SO_4\ MgSO_4\ 2CaSO_4\ 2H_2O$	12.9
6	Sylvite	KCl	52.4
7	Sylvinite	KCl NaCl	29.4

All the fertilizers potassium viz., KCl and K_2SO_4 used in India is imported as on today. Recently Geological Survey of India has reported the occurrence of K-deposits in Leh (Jammu and Kashmir) and Bikanir (Rajasthan) which await commercial exploitation.

Potassium schoenite a double salt of K_2SO_4 and Mg SO_4 obtain from salt bitterns is recently being produced on a pilot scale at Bhavanagar (Gujarat).

Manufacturing processes of potassium fertilizers

Two types of potassium fertilizers are widely produced in India

1. Potassium chloride (Muriate of potash)
2. Potassium sulphate (Sulphate of potash)

1. POTASSIUM CHLORIDE (KCl)/ [MOP]:

Potassium chloride is popularly known as muriate of potash [MOP]. The term muriate is derived from muriatic acid, a common name for hydrochloric acid (HCl)). It is the most important K-fertilizer used directly or in conjunction with P and N fertilizers.

Raw materials:

1. Sylvinite (or) brine

Unlike phosphate rock, K mineral salts do not require heat or strong acid treatment as they are water soluble. Potassium chloride is recovered, from sylvinite adopting either of the two processes viz.,

1. Crystallization process
2. Flotation process

1. Crystallization process:

Principle:

Crystallization process employed in separating potassium chloride from sodium chloride (Sylvinite: KCl .NaCl) is largely dependent on their different solubilities in hot (100 ^{0}C) and cold (20 ^{0}C) water. The solubility of KCl increases rapidly with a rise in temperature whereas the solubility of NaCl varies very slightly.

Cool brine (20 ^{0}C) saturated with both the slats is heated to (100 ^{0}C) and passes over the finely ground sylvinite ore, when KCl rich brine solution is obtained. It is cooled by vacuum evaporation which produces KCl crystals, which are centrifuged, washed, dried and packed. The filtrate (brine rich NaCl) is recycled for treating fresh ore.

2. Flotation process:

Separation of potassium chloride from its ore by mineral flotation is widely practiced all over the world relative to the crystallization process.

Principle:

Flotation is a separation process in which a solid treated with a selective agent is suspended in an aerated aqueous liquid. The treated solid adheres to the bubbles of air, and the froth is floated off the suspension. Non floating material is removed as pulp. The sylvinite ore is a mixture of interlocked crystals of potassium chloride and sodium chloride plus small quantities of clay and other impurities.

Raw material:

2. Sylvinite ore

Sylvinite ore is ground to a particle size of 10 mesh

1. Pulped in a saturated NaCl-KCl brine and scrubbed (Centrifuge) to disperse clay and other impurities.
2. The resultant slurry is thus deslimed in spiral classifiers to remove finely divided clay slimes.
3. Deslilming or removal of clay is the most important step since these material consume large quantities of flotation reagents.
4. The deslimed slurry relatively free of clay is treated with binding agents such as starch or mannogalactan gums.
5. The reagents used for sylvinite flotation is a mixture of primary aliphatic amine salts derived from beef tallow, which selectively film the sylvinite particle so that they will float.
6. The conditioned slurry is carried to flotation cells where air is drawn into the slurry.
7. The air bubbles attach themselves to the reagent treated sylvinite particle in the pulp causing them to float to the surface as froth, which is mechanically skimmed off by paddles.
8. The concentrate rich in KCl is further purified by sending it to cleaner cells to remove residual NaCl.
9. The MOP is separated from brine by centrifuging and drying in rotary driers, screened to a desirable particle size and finally sent for product storage.

Physical properties of MOP:

1. MOP in pure form is white crystalline salt. However, colour ranges from white to red based on the impurities present in K minerals and methods of refinement.
2. It has a solubility of 37 grams per 100 grams of water at 30 ^{0}C.
3. The crystalline MOP is not very hygroscopic ,flows freely and does not cake
4. Has specific gravity is 1.98.

Chemical properties of MOP:

1. MOP contains 58% by weight of K_2O and about 47 % chloride.
2. MOP is neutral in reaction and does not produce acidity and alkalinity on soil application.

2. POTASSIUM SULPHATE (K_2SO_4) /[SOP]:

The entire potassium sulphate fertilizer used in India is imported and it is more expensive than MOP.

Raw materials:

The manufacturing process is of two types viz.,

1. Langbeinite process
2. Mannheim furnace process

1. Langbeinite process:

The ore Langbeinite is a double sulphate of potassium and magnesium (K_2SO_4 2Mg SO_4).

In this process Langbeinite is ground and dissolved in water and concentrated solution of KCl (brine) is added ,when the potassium sulphate precipitates and is separated by centrifuging. The wet material is dried, screened and sent to storage. The chemical reaction involved is

$$K_2SO_4\ 2Mg\ SO_4 + 4KCl \rightarrow 3\ K_2SO_4 + 2MgCl_2$$

2. Mannheim furnace process:

In this process, potassium chloride (KCl) is reacted with sulphuric acid in a special furnace provided with rotary plough to form potassium bisulphate ($KHSO_4$) in exothermic reaction and to form potassium sulphate in endothermic reaction. HCl gas is evolved as a by product which is cooled and absorbed in water. Reactions that occur are-

$$KCl + H_2SO_4 \rightarrow KHSO_4 + HCl \rightarrow \text{[Exothermic reaction]}$$

$$KCl + KHSO_4 \rightarrow K_2SO_4 + HCl \rightarrow \text{[Endothermic reaction]}$$

Physical properties of SOP

1. Potassium sulphate [SOP] is a white crystalline salt, less hygroscopic as compared to MOP and free flowing.
2. It has specific gravity of 2.66 and has a solubility of 13 g/100 grams of water at 30 ^{0}C.

Chemical properties of SOP:

1. SOP contains 48 % K_2 O and 18 % S by weight.
2. Like MOP, it is also neutral salt providing neither acidity nor alkalinity on soil application.
3. The SOP is widely desirable .The chloride content of KCl effects the burning quality of tobacco. Never use KCl (MOP) on tobacco crop.

Mode of action of K fertilizers in soils or reactions of fertilizers in soils

1. Water soluble and as such act rapidly
2. In the soil K-fertilizers first enters the soil solution, but most of it directly absorbed on the complex and stored as loosely bound K and easily available to plants.

Secondary and micronutrient fertilizers

(A) Secondary fertilizers [Ca, Mg and S]

1. Calcium Fertilizers:

Nearly all multi nutrient liquid fertilizer formulations and more than 50 per cent multi nutrient solid fertilizers are almost devoid of calcium .Multi nutrient fertilizers use, warrants the use of calcium. The source of calcium with basic chemical formula, its content and solubility are mentioned in the following table.

Basic chemical data of various calcium sources:

S.No.	Source	Formula	Ca (%)	Water solubility g/100 g at 25 ^{0}C
1	Burnt lime	CaO	70	0.12
2	Hydrated lime	$Ca(OH)_2$	50	0.16
3	Calcite lime	$CaCO_3$	36	0.01
4	Dolamitic lime	$CaCO_3$ $Mg CO_3$	17	>0.1
5	Basic slag	$[CaO]_5$ P_2O_5 SiO_2	29	>0.1
6	Gypsum	$CaSO_4$ $2H_2O$	22	0.24
7	Calcium nitrate	$Ca(NO_3)_2 2H_2O$	20	100
8	SSP	$Ca(H_2PO_4)_2$ $CaSO_4$	20	1.0
9	TSP	$Ca(H_3PO_4)_2$	13	1.80
10	Rock phosphate	$Ca_5(PO_4)_3F$	33	0.002
11	Calcium chloride	$CaCl_2$	36	100.00

Global reserves of Ca are considerably large since whole mountain ranges consist of lime stone. Calcium nick named as root developer, which is slightly mobile in plants. Calcium deficiency in plants is rarely caused by shortage of available reserves in the soil, except in acidic soils.

2. Magnesium Fertilizers:

In multi nutrient fertilizers, finely ground dolamitic limestone is used as filler and it is a incidental supplier of Mg.

S.No.	Source	Formula	Mg (%)	Water solubility g/100 grams at 25 ^{0}C
1	Magnesium oxide	MgO	45	6.2 x10 $^{-5}$
2	Dolamite	$CaCO_3$ $MgCO_3$	12	0.032
3	Kiserite	$MgSO_4$ H_2O	18.2	68.40
4	Langbeinite	K_2SO_4 $2MgSO_4$	11.2	100.0
5	Magnesium sulphate	$MgSO_4$ $7H_2O$	10.5	91.10

3. SULPHUR FERTILIZERS:

1. Plants take sulphur in the form of sulphate [SO_4^{2-}] ion. Sulphur fertilizers predominantely contain sulphate, some of which are easily soluble and some are slightly soluble
2. Gypsum [$CaSO_4$ $2H_2O$] is a calcium sulphate because its slight solubility in water which is slow acting
3. Elemental sulphur is also an important sulphur fertilizer with strong acidifying action. It can be used either directly or as an additive to other solid fertilizers eg sulphur coated urea. The following table gives the basic chemical data of sulphur sources

S.No.	Source	Formula	S (%)
1	Ammonium sulphate	$(NH4)_2$ SO_4	23
2	Potassium sulphate	K_2SO_4	18
3	Magnesium sulphate	$MgSO_4$	13
4	Super phosphate	$Ca(H_2PO_4)_2$ $CaSO_4$	12
5	Gypsum	$CaSO_4$ $2H_2O$	18
6	Aluminium sulphate	$Al_2(SO_4)_318H_2O$	14

The sulphur requirements of plants are approximately 2/3 of their phosphorus requirements and are provided from various sources such as air, rain water, soil and fertilizer. Fields near Industrial zones are supplied with 10-30 kg ha $^{-1}$ per year from SO_2 waste gases.

MICRONUTRIENT FERTILIZERS

Higher green plants are known to require seven micronutrients viz.,Fe,Mn Cu, B Mo ,Cl etc., . But this number may have to be increased in future.

Sources of micronutrients:

S.No.	Micronutrients	Formula	Content (%)
A	**IRON**		
	1.Ferrous sulphate	$FeSO_4\ 7H_2O$	20
	2.Fe-chelate	Fe-EDTA	5
	3.Fe-Chelate	FeEDHA	6
B	**MANGANESE**		
	1. Manganous sulphate	$Mn\ SO_4\ 4\ H_2\ O$	24
	2.Manganous sulphate (Monohydrate)	$Mn\ SO_4\ \ H_2\ O$	32
	3. Mn –chelate	Mn-EDTA	13
C	**ZINC**		
	1.Zinc sulphate	$ZnSO_4\ 7H_2O$	23
	2.Zinc sulphate (Monohydrate)	$ZnSO_4\ H_2O$	36
	3.Zn-chelate	Zn-EDTA	14
D	**COPPER**		
	1.Copper sulphate	$Cu\ SO_4\ 5H_2O$	25

	2.Copper sulphate (Monohydrate)	$Cu SO_4\ H_2O$	36
E	**BORON**		
	1. Borax (Na-tetra borate)	$Na_2B_4O_7\ 10H_2O$	11
	2.Borax anhydrous	$Na_2\ B_4O_7$	22
	3.Boric acid	H_3BO_3	18
F	**MOLYBDENUM**		
	1 Sodium molybdate	$Na2MoO_4\ 2H_2O$	40
	2.Ammonium molybdate	$(NH4)_6MoO_{24}$	54
	3Molydenum trioxide	MoO_3	66
	4.Calcium molybdate	$CaMoO_4$	48

The need for the micronutrient fertilization has been increasing due to the following causes:

1. Change in the plants:

Change in the plant varieties from traditional to high yielding varieties (HYV). HYV have a capacity to remove more nutrients both major and minor. HYV have low mobilizing capacity of micro nutrients from the soils hence they are to be applied through external application.

2. **Change in soil**:

Change in soil condition from acid to alkaline (Increased soil reaction) and aeration cause greater immobilization of most micronutrients except molybdenum (Fe, Zn, Cu and Mn). High acidic nature of the soil induces both calcium and magnesium deficiency.

3. Changes in fertilization: Using high doses of NPK in the form of complex fertilizers, induces deficiencies of secondary and micro nutrients.

1. Antagonistic action due in part to excessive fertilization with NPK Eg. Higher K content in soils effects the uptake of Fe, Mn, and B.
2. Excess P leads to deficiencies of Zn, Fe, Cu and increases Mo availability.
3. More the sulphate present in the soils, lesser the availability of Mo.
4. Lesser or least micronutrient constituents in multinutrient fertilizers.

4. Changes in overall growth conditions.

1. Intensive cultivation: Intensive cultivation leads to micro nutrient deficiencies
2. Non availability and application of organic manure.
3. Under/ over limed condition.
4. Parent material: Most of the micronutrients originates from parent material and influences the availability or deficiency of micronutrients to plants
5. Land levelling and shaping: Most of the micronutrients are concentrated on the surface soil except Molybdenum. Levelling of land and deep tillage operations leads to deficiencies.
6. Low Si/Mg ratio: Leads to fixation of Zn in soil.
7. Calcium carbonate: More the $CaCO_3$ in soils lesser the availability of Fe, Cu, Mn, Zn.
8. Soil texture: Boron availability is more in coarse textured soils and in finer textured soils it gets fixed, unavailable to plants.
9. Secondary clay minerals: Montmorillonite clay adsorb more of Zn, Cu and leads to deficiency or unavailability to plants.
10. Soil moisture: Dry conditions of soil fix more of Boran and is released under wet conditions. Presence of more moisture reduces the availability of Mn.
11. Interaction with macronutrients: Heavy nitrogen interferes with availability of Cu, Mn, Zn and leads to deficiencies in plant.
12. Liming reduces the availability of Mn, Zn, Fe, Cu.
13. Seasonal variation: Nutrient deficiencies are more during cold season.
    - Out break of B deficiency is common in dry seasons
    - Summer drought aggravate Fe chlorosis.
    - High and low soil temperatures induces Zn deficiency in soils having low Zn.

PRINCIPLES INVOLVED IN MICRONUTRIENT FERTILIZATION

1. Iron Fertilization:

Majority of Fe-fertilizers are water soluble .Salts or organic complexes (chelates). They are predominantly applied as foliar sprays, however this requires repeated application. In addition to supplying iron to deficit soils, it is necessary to mobilize iron in the soil itself through acid –N – fertilization. Fe removal amounts to a few kg/ha /year

2. Manganese Fertilization:

Manganese sulphate is the best known water soluble fertilizer and is suitable for leaf fertilization .It can also be used as a soil dressing, but is easily fixed in deficit soils when the pH is more soil Mn supplies can be improved by

1. Using acid forming fertilizers
2. Compacting loose soils
3. Preventing excessive drying
4. Supply of easily decomposed organic matter ,which on conversion creates reducing conditions and thus Mn released .It is a practical means of Mn supply than to add Mn fertilizer. About ½ to 1.0 kg of Mn /ha/year is removed by crops in general.

3. Copper Fertilization:

Copper sulphate [Blue Vitriol] is the oldest water soluble Cu-fertilizer .It can be applied as soil dressing or foliar nutrient .However; its acidic side effects are likely to cause leaf scorch on foliar application.

1. Hence less caustic agents like green copper $Cu_2Cl(OH)_3$ or Cu-chelates are safe to use.
2. Copper removal by crops in general varies 30-100 g/ha /year.
3. Copper is highly immobile in soil and as such needs thorough mixing with top soil.

4. Zinc Fertilization:

Zinc sulphate is the simplest form of water soluble fertilizer

1. It is acidic in reaction and causes leaf scorch on foliar application unless free acidity in neutralized with lime**.**
2. Improvement of natural zinc sulphate (Soil zinc) can be done by the application of acid forming N-fertilizers to combat Zn-deficiency. Crop removal of Zn varies from 100-400 g /ha /year

5. Boron Fertilization:

Borax (Na –tetra borate) is historically famous water soluble boron fertilizer.

1. The effectiveness of chile –salt peter was attributed to the presence of borax as natural admixture.
2. It can be applied to soil or foliage
3. Boron removal by crops is about 50 g / ha /year

6. Molybdenum Fertilization:

Sodium molybdate and ammonium molybdate are the important Mo fertilizers suitable for soil or foliar application and also for seed treatment.

1. Molybdenum removal by crops varies from 5 to 20 g/ha /year

Classification of micronutrient fertilizers

Micronutrient fertilizers are classified into two broad categories:

1. Inorganic salts
2. Chelates

1. Inorganic salts:

Supplying micronutrients are salts like ZnSO4, CuSO4, MnSO4, Fe SO4 etc., All these are readily soluble in water and can be used both for soil application and foliar spray.

2. Chelates:

This is next important category of micronutrient fertilizers. Chelates are metallic molecules of varying sizes and shapes in which the organic part binds the nutrient in a ring like structure. For the chelation of nutrient cation the common chelating agents used in chelating micronutrients as follows.

1. EDTA : Ethylene Diamine Tetra Acetic Acid
2. HEDTA : Hydroxy Ethylene Diamine Tetra Acetic Acid
3. EDDHA : Ethylene Diamine Dihyroxy Acetic Acid
4. NTA : Nitrilo Tri Acetic Acid
5. DTPA : Diethylene Triamine Penta Acetic Acid

NPK Complex Fertilizers

N P K complexes are the fertilizers which are granular containing three major plant nutrients .Different grades of these fertilizers are being manufactures in India viz., 17-17 -17; 14-35-14; 14-28-14; 10-26 -26; 12-32-16 etc.,

Manufacturing process:

Raw material: 1) Ammonia. 2) Phosphoric acid. 3) Potassium chloride. 4) Urea.

Ammonia and phosphoric acid are mixed in a specified proportion in the pre neutralizer and the resultant slurry is pumped to a granulator [Rotating drum] where nitrogen content of the product is enriched by adding more ammonia and feeding in urea. Potassium chloride is also added to make up the required formulation .Filler like sand or dolomite is also added to improve the handling property of the fertilizer product.

Physical properties:

1. NPK complexes are grey or cream coloured granules. They are free flowing with good storage properly.
2. Exposure to high humidity however can cake hence to be packed in polyethylene lined gunny bags.

Chemical properties:

N P K complex grade - 17 : 17 : 17

- It contains 5% ammonical and 12 % aminde N
- 15% water soluble and 2 % citrate soluble P_2O_5
- 17% water soluble K_2O

Grade- 14:35:14

- All N in ammonical form 14%
- 29% water soluble and 6% citrate soluble P_2O_5
- 14 % water soluble K_2O

Salient feature of complex fertilizer: If we analyze any granule from particular grade, it should contain the same ratio with respect to N, P and K.

AMENDMENTS

Soil amendments are substances that influence the plant growth favorably by producing in the soil one or more of the following beneficial effects.

1. Changing the reaction, that is making the soil less acidic or less alkaline ;
2. Changing the plant nutrients in the soil from unavailable to available forms;
3. Improving the physical conditions of the soil and
4. Counteracting the effects of injurious substances

Soil amendments usually contain plant nutrients also. Agricultural liming materials, for example, supply calcium and, sometimes magnesium as nutrient element.

Types of soil amendments

Mainly there are three types of soil amendments

1. Materials for correcting acidic soil
2. Materials for correcting alkaline soils
3. Soil aggregating agents or soil conditioner s to stabilize soil aggregates and to form granular structure.

Fertilizer Control Order (FCO)

Objectives:

Laws and regulations governing the manufacture and sale of fertilizers are imperative in order to check

1. Spurious standards and adultrated fertilizers entering in to the market.
2. To ensure quantity of nutrients and quality of carriers present in the fertilizer.
3. To ensure quantity of nutrients and quality of carriers present in the fertilizer.
4. To eliminate black marketeers off the market.
5. The total N,P_2O_5 and K_2O must be guaranteed in terms of percentage of each of these nutrients in a given fertilizer .The oxide expression for P and K are actually in accurate and confusing as they are based on early practices with which chemists determined the elements by ignition and weighing the oxides. The current practice is to express the elemental concentration of these nutrients.

By considering the above said objectives, the government of India passed. The FERTILIZER CONTROL ORDER [FCO] on 28th of April, 1957 in exercise of the power conferred by the section III of the essential commodities act of 1955. This order is intended to regulate the manufacture, distribution and supply of the fertilizers in India at a control cost. This has been effective from May 18th 1957. It is revised in 1985 with effect from 25-9-1985. The Government of India has delegated to powers to state Governments to implement the order.

The Government of India (G O I) also passed the Fertilizer Movement Order (FMO) on 31st December, 1960 in order to regulate the inter state movement of fertilizers and the export of fertilizers which came into force with effect from 1-1-1961.

Fertilizer Control Order [FCO] Regulations:

1. All the fertilizer manufacturer should obtain licence from the Commissioner of Agriculture ,state Government concerned for the manufacture of fertilizer and mixed fertilizers.
2. The fertilizer dealers should on renewable basis, register their dealership with the Assistant Director of the Agriculture (ADA) Regular of the division concerned in a state.
3. The terms and conditions of manufacture, distribution and sales imposed by the government should be followed.
4. Duties of inspecting officers and the dealers are specified.
5. Fertilizer specifications and kind of package are stated.
6. Method of drawing fertilizer samples for analysis in the fertilizer testing laboratories is stated.
7. Powers are vested with the FCO enforcing officials to book the cases against the fraudulent manufacturers, distributors and dealers of fertilizers.

Specifications and standards for important fertilizers [As per FCO, 1957]

1. **Urea**
    1. Moisture per cent by weight 1.0 Maximum
    2. Total nitrogen per cent by weight 44.0 minimum
    3. Biuret per cent by weight 1.50 maximum
    4. Particle size: In the form of granule the material shall pass through2.8mm and not less than 80% by weight shall be retained on 1mm
2. **SSP**
    1. Moisture per cent by weight, maximum 12
    2. Free phosphates as (P_2O_5) percent by weight 4.0
    3. Water soluble phosphates (as P_2O_5) by weight maximum 16.0

3. **MOP**
    1. Moisture per cent by weight maximum 12.00

4. **DAP**
    1. Moisture per cent by weight 1.0
    2. Total nitrogen per cent by weight minimum 18
    3. Total phosphates (as P_2O_5) per cent by weight minimum 46.0
    4. Water soluble phosphates (as P_2O_5) per cent by weight 41.6

Soil fertility– Concepts of soil fertility and soil productivity. Soil as a source of plant nutrients.

As civilization moves to beginning of the twenty first century and as World's population continues to increase, the importance of a continuing increase in food production is obvious. India alone is contributing more than a Billion people. It means that our crop production must be at least doubled by the end of the century. There are two options open to us. One way is to increase the area under the plough and the other to increase production per unit area. The scope is limited for the first option. So greater attention will have to be paid to the increasing of the production per unit area, per unit time. The strategy is to maintain soil fertility and proper nutrient management without impairing soil quality (sustainable agriculture).

Soil fertility: Soil fertility is defined as the quality that enables the soil to provide proper nutrient compounds in proper amounts and in proper balance for the growth of specified plants. Soil fertility is also defined as the ability of soil to supply adequately the nutrients normally taken from the soil by plants.

Soil Chemistry: It deals with the chemical constitution of the soil - the chemical properties and the chemical reactions in soils. It is the study of chemical composition of soil in relation to crop needs. Traditional soil chemistry focuses on chemical and biochemical reactions in soils that influence nutrient availability for plant growth, and potential environmental consequences associated with inorganic and organic fertilization. Soil chemistry has increasingly focused on the environment over the past few decades, especially as related to ground and surface water quality. Understanding the reactions and biogeochemical processes of potential pollutants and contaminants in soils will enable a more accurate prediction of fate and toxicity of contaminants, and development of remediation strategies.

The overall goal of soil chemistry/fertility research is a more fundamental understanding of chemical and biochemical reactions in soils related to plant growth, sustainability while maintaining soil and environmental quality. Soils are the medium in which crops grow to provide food and cloth to the world. Soil is the major factor that limits the type of vegetation and crops. Under similar climatic conditions, a loose and porous soil that retains little water will support sparse vegetation when compared to deep, fertile loam or clay. The basic need of crop production is to maintain soil fertility and soil productivity.

Soil fertility and Soil productivity

Soil fertility		Soil productivity	
1	It is the inherent capacity of the soil to provide essential chemical elements for plant growth	1.	Soil productivity emphasizes the capacity of soil to produce crops and is expressed in terms of yield.
2	A combination of soil properties and an aspect of soil – plant relationships.	2.	An economic concept and not a property of soil
3	Soil fertility is vital to a productive soil. But a fertile soil is not necessarily be a productive soil. Many factors can limit production, even when fertility is adequate. For eg., soils in arid region may be fertile but not productive.	3.	Soil fertility is one factor among all the external factors that control plant growth like air heat (temp.), light, mechanical support, soil fertility and water. Plant depends on soil for all these factors except for light.
4	Organic matter in the soil improves soil fertility by mineralization of nutrients.	4.	Organic matter also improves soil productivity by improving soil porosity, aggregation and physical condition of soil thus modifying the soil environment for crop growth.

Concepts of soil fertility and soil productivity

- It is evident from the early writing of Theophrastus (372 – 287 BC) even before the advent of Christian era, Greek and Romans realized the impact of soil on the growth of plants and made a mention about the application of organic wastes and saltpeter for the plants.

- The first experiment aimed at elucidating the increase in the weight of plant during its growth was reported by Nicholas (1401 - 1446).
- Jan Baptiste van Helmont (1577-1644) attributed the increase in weight of willow shoot to water.
- But a German chemist, Glauber (1604-1668), who attributed the growth of plants to the absorption of saltpeter (KNO_3) from the soil.
- John Woodward (during the year about 1700) first conducted water culture experiments on spearmint and emphasised that the growth factor is some terrestrial matter but not the water.
- Jean Baptiste Boussingault (1802-1882) carried out field plot experiments. He was called as ‘father of field plot technique’.
- Justus von Liebig (1803-1873) put forth the ‘law of minimum’ which states that the yield is governed by the limiting nutrient and is directly proportional to the factor which is minimum in the soil.

Soil as a source of plant nutrients

Soils are complex natural formations on the surface of the earth and consist of five main components: mineral matter, organic matter, water, air and living organisms. The rocks and minerals on weathering release nutrients into the soil. The most important part of the soil with respect to plant nutrition is the colloidal fraction which consists of inorganic colloids (clay) and organic colloids (humic substances). Most of soil colloids possess electronegative adsorption sites available for attracting cations including calcium, magnesium, potassium, ammonium etc as well as H^+ arising from the biological activity. Organic matter on decomposition releases nutrients. The cations adsorbed on the surface of the colloids are capable of exchanging rapidly and reversibly with those in soil solution. The principal immediate source of mineral nutrients to plant roots is ions in the soil solution. This nutrient supply is gradually depleted by absorption of nutrient ions by plant roots and continuously replenished by desorption of exchangeable ions on the clay-humus complex and break down of readily decomposable organic debris. The microbes in the soil also help in supplementing nutrients by the way of nutrient transformations. These sources represent the reserves that serve to replace but only at a relatively slow rate. For intensive cultivation of crop plants, however, application of mineral salts to soil is required.

Nutrient elements: Arnon's criteria of essentiality – essential, functional and beneficial elements

The criteria of essentiality put forth by Arnon

In the nature there are nearly one hundred and three elements. Of them nearly ninety elements are taken in by the plants. In order to distinguish the elements which are essential from those which may be taken in by the plants but are not essential, Arnon (1954) has laid down the following criteria.

1. The plant must be unable to grow normally or complete its life cycle in the absence of the element.
2. The element is specific and cannot be replaced by another.
3. The element plays a direct role in plant metabolism.

It appears that an element would have to be considered essential even if it has not been possible to demonstrate that it fulfills the second criterion of essentiality. For ex., for many bacteria, diatoms and other algae, vitamin B_{12} is known to be essential, but the essentiality of cobalt per se has not been demonstrated. According to this criterion, molybdenum and chlorine cannot be considered as essential though they are functional in plant metabolism since they can be replaced by vanadium and halides respectively. D.J. Nicholas gave more exact definition of essential elements and advanced the term "functional or metabolic nutrient" to include any mineral element that functions in plant metabolism, whether or not its action is specific.

Element	Essentiality was established by	Year
H, O	---	Since time immemorial
C	Priestly *et al*.	1800
N	Theodore de Saussure	1804
P, K, Mg, S	C Sprengel	1839
Fe	E Gris	1843
Mn	JS Mc Hargue	1922

Zn	AL Sommer and CP Lipman	1926
Cu	AL Sommer, CP Lipman and G Mc Kinney	1931
Mo	DI Arnon and PR Stout	1939
Na	Brownell and Wood	1957
Co	Ahmed and Evans	1959

II. Elements accepted as essential for higher plants only

Ca	C Sprengel	1839
B	K Warington	1923
Cl	Broyer, Carlton, Johnson and Stout	1954

Element	**Group or plant sp**	**Essential requirement**	**Year**
Vanadium	*Scenedesmus Obliquus*	DI Arnon and G. Vessel	1953
Silicon	Diatoms	J.C. Lewin	1962
Iodine	Polysiphonia	L. Fries	1966
Selenium	Astragalus sp.	SF Trelease and HM Trelease	1938
Gallicum	*Aspergillus niger*	RA Steinberg	1938
Aluminium	Ferns	K. Taubock	1942

Terminology

Plant nutrition:

Plant nutrition is defined as the supply and absorption of chemical compounds required for plant growth and metabolism. It is the process of absorption and utilization of essential elements for plant growth and reproduction.

Nutrient:

Nutrient may be defined as the chemical compound or ion required by an organism. The mechanism by which the nutrients are converted to cellular material or used for energetic purposes are known as metabolic processes.

Beneficial elements:

The elements, the essentiality of which for growth and metabolism has not been unequivocally established, but which are shown to exert beneficial effects at very low concentrations are often referred to as beneficial elements, or potential micronutrients. The beneficial effect of these nutrients may be due to the ability of these elements affecting the uptake, translocation and utilization of the essential elements. They may be essential only for certain plant species or under specific conditions. Eg : Silicon, vanadium, cobalt and aluminium.

Functional element:

Nicholas D J (1961) advanced the term functional or metabolic nutrient to include any mineral element that functions in plant metabolism whether or not its action is specific.

To describe the level of nutrient element in plants the following terms are proposed.

1. **Deficient**: When an essential element is at low concentration that severely limits yield and produces more or less distinct deficiency symptoms.
2. **Toxic**: when the concentration of either essential or other element is sufficiently high to inhibit the plant growth to a great extent.

Forms of nutrient elements absorbed by plants

i) Absorbed as single nutrient ion

Nutrient element	Forms absorbed by plants
Potassium	K^+
Calcium	Ca^{2+}
Magnesium	Mg^{2+}
Iron	Fe^{2+}
Manganese	Mn^{2+}
Copper	Cu^{2+}
Zinc	Zn^{2+}

Chlorine	Cl^-
Silicon	Si^{4+}
Cobalt	Co^{2+}
Sodium	Na^+

ii) Absorbed in a combined form

Nitrogen	Ammonium (NH_4^+) and Nitrate (NO_3^-)
Phosphorus	$H_2PO_4^-$, $HPO_4^=$
Sulphur	$SO_4^=$
Boron	H_3BO_3, $H_2BO_3^-$, HBO_3^{2-}, BO_3^{3-}
Molybdenum	$MoO_4^=$ (Molybdate)
Carbon	CO_2
Hydrogen	H_2O

Classification of essential nutrients:

Nutrients are chemical compounds needed for growth and metabolic activities of an organism. The essential plant nutrients may be divided into macronutrients (primary and secondary nutrients) and micronutrients.

(A) Macronutrients

Macronutrients or major nutrients are so called because they are required by plants in larger amounts. These are found and needed in plants in relatively higher amounts than micronutrients. They include C, H, O, N, P, K, Ca, Mg and S. C, H and O constitute 90 – 95 per cent of the plant dry matter weight and supplied through CO_2 and water. Remaining six macronutrients are further sub divided into primary and secondary nutrients.

Primary nutrients: Nitrogen, phosphorus and potassium are termed as primary nutrients because the correction of their wide spread deficiencies is often necessary through the application of commercial fertilizers of which these are the major constituents.

Secondary nutrients: Calcium, magnesium and sulphur are termed as secondary nutrients because of their moderate requirement by plants, localised deficiencies and their inadvertent accretions through carriers of the primary nutrients. For example, the phosphatic fertiliser, single super phosphate (SSP) contains both Ca and S. Similarly, ammonium sulphate, a nitrogenous fertiliser also supplements S.

(B) Micronutrients:

Micronutrient is an element that is required in relatively small quantities but is as essential as macronutrients. These elements have often been called trace elements. They are again classified into micronutrient cations (eg. Fe, Mn, Zn and Cu) and micronutrient anions (eg., B, Mo and Cl) depending upon the form in which they are available.

This above division of plant nutrients into macro and micro nutrients is some what arbitrary and in many cases, the differences between the contents of macronutrients and micronutrients are considerably less well defined. Therefore, classification of plant nutrients according to biochemical behaviour and physiological functions seems more appropriate. The classification of plant nutrients is as below:

Essential plant nutrient	**Biochemical functions**
1st group	
C, H, O, N, S	Major constituent of organic material, essential elements of atomic groups which are involved in enzymatic processes and assimilation by oxidation – reduction reactions.
2nd group	
P, B, Si	Etherification with native alcohol groups in plants. Involved in energy transfer reactions.
3rd group	
K, Na, Mg, Ca, Mn, Cl	Non specific functions establishing osmotic potentials; enzyme activation, balance of ions, Controlling membrane permeability and electro potentials.
4th group	
Fe, Cu, Zn, Mo	Present predominantly in a chelated form incorporated in prosthetic groups.

Mobile	Partly mobile	Immobile
1. Nitrogen	1.Iron	1.Calcium
2. Phosphorus	2. Zinc	2.Sulphur
3. Potassium	3. Copper	3.Boron
4. Magnesium	4.Molybdenum	

Mobile nutrient:

Mobile nutrients are those when deficient in the plant, move from the matured tissue (older leaves) to the young meristem thus the deficiency symptoms are manifested on the older tissue.

Immobile nutrient:

Immobile nutrients are those which under the situation of deficiency in the soil cannot move from older to younger tissue and hence the deficiency symptoms appear first on the younger leaves.

Chapter - 17

Role and deficiency symptoms of essential plant nutrients

Nitrogen

Symbol: N; Available to plants as nitrate (NO_3^-) and ammonium (NH_4^+) ions.

Nutrient functions

- N is biologically combined with C, H, O, and S to create amino acids, which are the building blocks of proteins. Amino acids are used in forming protoplasm, the site for cell division and thus for plant growth and development.
- Since all plant enzymes are made of proteins, N is needed for all of the enzymatic reactions in a plant.
- N is a major part of the chlorophyll molecule and is therefore necessary for photosynthesis.
- N is a necessary component of several vitamins.
- N improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops.

Deficiency symptoms

- Stunted growth may occur because of reduction in cell division.
- Pale green to light yellow color (chlorosis) appearing first on older leaves, usually starting at the tips. Depending on the severity of deficiency, the chlorosis could result in the death and/or dropping of the older leaves. This is caused by the translocation of N from the older to the younger tissues.
- Reduced N lowers the protein content of seeds and vegetative parts. In severe cases, flowering is greatly reduced.
- N deficiency causes early maturity in some crops, which results in a significant reduction in yield and quality.

Phosphorus

symbol: P; Available to plants as orthophosphate ions ($HPO_4{}^{2-}$, $H2PO_4^{-}$).

Nutrient functions

- In photosynthesis and respiration, P plays a major role in energy storage and transfer as ADP and ATP (adenosine di- and triphosphate) and DPN and TPN (di- and triphosphopyridine nucleotide).
- P is part of the RNA and DNA structures, which are the major components of genetic information.
- Seeds have the highest concentration of P in a mature plant, and P is required in large quantities in young cells, such as shoots and root tips, where metabolism is high and cell division is rapid.
- P aids in root development, flower initiation, and seed and fruit development.
- P has been shown to reduce disease incidence in some plants and has been found to improve the quality of certain crops.

Deficiency symptoms

- Because P is needed in large quantities during the early stages of cell division, the initial overall symptom is slow, weak, and stunted growth.
- P is relatively mobile in plants and can be transferred to sites of new growth, causing symptoms of dark to blue-green coloration to appear on older leaves of some plants. Under severe deficiency, purpling of leaves and stems may appear.
- Lack of P can cause delayed maturity and poor seed and fruit development.

Potassium

Symbol: K; Available to plants as the ion K^+

Nutrient functions

- Unlike N and P, K does not form any vital organic compounds in the plant. However, the presence of K is vital for plant growth because K is known to be an enzyme activator that promotes metabolism.
- K assists in regulating the plant's use of water by controlling the opening and closing of leaf stomates, where water is released to cool the plant.
- In photosynthesis, K has the role of maintaining the balance of electrical charges at the site of ATP production.
- K promotes the translocation of photosythates (sugars) for plant growth or storage in fruits or roots.
- Through its role assisting ATP production, K is involved in protein synthesis.
- K has been shown to improve disease resistance in plants, improve the size of grains and seeds, and improve the quality of fruits and vegetables.

Deficiency symptoms

- The most common symptom is chlorosis along the edges of leaves (leaf margin scorching). This occurs first in older leaves, because K is very mobile in the plant.
- Because K is needed in photosynthesis and the synthesis of proteins, plants lacking K will have slow and stunted growth.
- In some crops, stems are weak and lodging is common if K is deficient.
- The size of seeds and fruits and the quantity of their production is reduced.

SECONDARY NUTRIENTS

Secondary nutrients include calcium, magnesium and sulphur. These nutrients received little attention due to their inadvertent application through fertilizers and irrigation water. Ammonium sulphate (100 kg) supplies 20 kg N and 24 kg S; While single super phosphate supplies 16 kg of P_2O_5, 21 kg of Ca and 12 kg of S. Potassium sulphate supplies 52 kg K_2O and 18 kg of S. These secondary nutrients though required in equal amounts as primary nutrients, but are added inadvertently along with primary nutrients. Lime which contains Ca and Mg is applied to raise the pH and sulphur compounds are used to lower the pH of soil. Irrigation water may contain on an average 25 ppm of SO_4 =, 50 ppm of Ca and 5 ppm of Mg.

Calcium

Functions of calcium in plants

Calcium is absorbed by the plant as calcium ions (Ca2+), the sufficiency range is between 0.2 – 1.0 %.

1. Essential for the formation of cell wall and calcium pectate in the middle lamella of the cell wall which regulates the entry of only those nutrients which are not toxic to plants. In seeds, calcium is present as calcium phytate.
2. In root tip, calcium is very essential for the meristematic activity.
3. Provides a base for neutralisation of organic acids and other toxins (like Al) produced in plants.
4. It plays a role in mitosis (cell division) and helps to maintain the chromosome structure.
5. Essential co-factor or an activator of a number of enzymes like hydrolases.
6. It activates phospholipase, argnine kinase, amylase and Adenosine tri phosphatase (ATPase) enzymes.
7. Favours the assimilation of nitrogen into organic constituents especially proteins.

Deficiency symptoms

Soils seldom become calcium deficient, as long as soil pH is maintained towards neutral range. Deficiency of calcium is characterised by a reduction in meristematic tissue

1. Though calcium is highly mobile in soil, in the plant system it is the immobile nutrient and hence the deficiency symptoms manifest at the growing tips of shoots and youngest leaves.

2. Failure or desiccation of terminal bud development.

3. No unfolding of new leaves in corn, whose tips are colorless and are covered with sticky gelatinous material which makes them adhere to one another.

4. Chlorosis of young leaves followed by distortion of the growing points of the stem.

5. In fruit trees, the death of growing points followed by die back.

6. In guava, the old leaves are chlorotic with red brown spots.

7. In apple, the discoloration of the fruit meat, the condition generally referred to as “bitter pit”.

8. In Brassica, severe loss of color in young leaves, terminal bud leaves are hooked, leaves below become cup shaped. Old leaves collapse due to terminal bud disintegration.

9. Blossom end rot in tomato is due to Ca deficiency.

Magnisium

Functions

- The usual concentration of Mg+2 in crops varies between 0.1 and 0.4 per cent. A large part of Mg is associated with organic anions like malate.
- Mg is the only mineral constituent of chlorophyll located at its centre. Chlorophyll formation usually accounts for about 15 to 20 % of total Mg content of plants as Mg - porphyrin.
- Serves as a structural component of ribosomes. Mg activates the formation of polypeptide chains to form amino acids. About 70 % of Mg is associated with anions such as malate and citrate.

- Seeds contain Mg as salt of phytic acids. Mg is required for phosphate transfer from ATP (Phosphorylation) in carbohydrate metabolism.
- Several enzymes (eg : Ribulose carboxylose) require Mg+2 as Cofactor.
- It promotes uptake and translocation of phosphorus and movement of sugars within the plants.

Deficiency symptoms :

- Mg^{+2} is a mobile element and is readily translocated from older to younger plant parts in the event of deficiency and hence deficiency symptoms are manifested in the older leaves. The magnesium deficient plants usually have less than 0.1% Mg. Magnesium deficiency is common in the plants grown on coarse textured acidic soils.
- As a consequence of Mg^{+2} deficiency, the proportion of protein nitrogen decreases and that of non protein nitrogen increases in plants.
- Shortage of Mg+2 results in an interveinal chlorosis of the leaf in which only the veins remain green and the interveinal areas turn yellow with streaky or patchy appearance. In more advanced stages the leaf tissue becomes uniformly pale yellow, then brown and necrotic.
- Affected leaves turn small in final stage and curve upwards at the margins.
- In some vegetables, interveinal chlorosis with tints of red, orange and purple colors is observed.
- Grass tetany : Cattle consuming forages with low Mg may suffer from "Hypomagnesemia" (low level of blood Mg) commonly known as Grass tetany. This happens due to high levels of NH_4^+ - N and K application.

Sulphur

Functions of sulphur in plants

1. It is required for the synthesis of the S containing amino acids cystein, cystine and methionine and for protein synthesis.
2. It activates certain proteolytic enzymes such as papainase and synthesis of papain.
3. It is a constituent of certain vitamins viz., Thiamine and biotin, coenzymes and glutathione, Acetyl coenz A (precursor for fatty acid synthesis), ferredoxin.
4. It is present in the crops like onion, mustard, cabbage and cauliflower as polysulfides.
5. It increases oil content of crops like flax, soybean, groundnut etc.
6. Disulfide linkages (-S-S -) have been associated with the structure of proteins.
7. Sulfhydryl (-SH) groups in plants are related to increased cold resistance.
8. It is required for N fixation in legumes and is a part of nitrogenase enzyme system.

Deficiency symptoms

Sulphur content in plants ranges between 0.1 to 0.4 %. In view of the large field scale occurrences of sulphur deficiencies in India, it has been described as the fourth major nutrient after N, P and K. Plants suffering sulphur deficiency accumulate non protein nitrogen in the form of nitrate and amide. N:S ratio of plants is between 9 to 12 : 1. As sulphur is immobile in the plant, its deficiency is manifested on young leaves.

1. The fading of normal green colour of the young meristem followed by chlorosis.
2. Shoot growth is restricted.
3. In Brassica, the lamina is restricted and the leaves show cupping owing to the curling of leaves.
4. The older leaves become puckered inwardly with raised areas between veins.
5. The older leaves may develop orange or reddish tints and may be shed prematurely.
6. The stem and leaf petiole may become brittle and may collapse.
7. Reduced synthesis of proteins and oil.

MICRO- NUTRIENTS

Zinc

Functions :

- Plants absorb zinc as Zn2+. Zinc sufficient plants contain 27 to 150 ppm Zn in mature tissue.
- Zinc is a constituent of three enzymes viz., Alcoholic dehydrogenase, carbonic anhydrase, superoxide dismutase (SOD).
- Zn is involved in the synthesis of indole acetic acid, metabolism of gibberellic acid and synthesis of RNA.
- Because of preferential binding to sulphydryl group, zinc plays an important role in the stabilization and structural orientation of the membrane proteins.
- Zn influences translocation and transport of P in plants. Under Zn deficiency, excessive translocation of P occurs resulting in P toxicity.

Deficiency symptoms

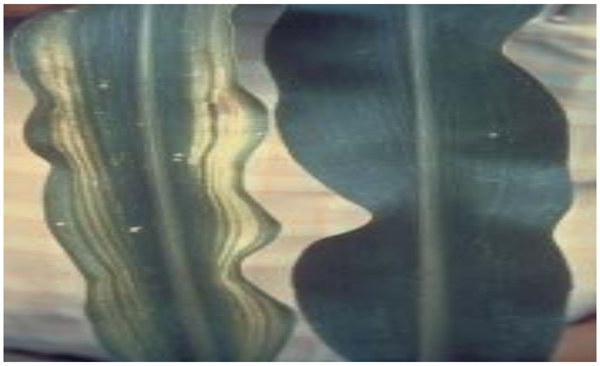
Zn deficiency symptoms show wide variation in different plant species. The common symptoms are chlorosis between the veins, reduction in the size of the young leaves, which are often clustered, bronzing, purple, violet, reddish brown or brown coloration of the foliage.

a) **Khaira disease of rice:** The first symptom of zinc deficiency appear in 3 – 4 week old seedlings when the young leaves develop reddish brown pigmentation. The pigmentation appears first in the middle of the leaves, then intensifies and spreads over the entire lamina. The affected tissue becomes papery and necrotic and under conditions of severe deficiency, the entire mass of leaves collapses and further growth of the plant is arrested.

2) White bud of maize : Soon after the emergence of seedlings, areas between the veins of old leaves become light yellow and develop white necrotic spots, which later develop dark brown necrotic areas that enlarge and coalesce, resulting in the necrosis (death of the entire leaf). Leaves that emerge and unroll subsequently appear yellow and white.

3) Mottle leaf or Frenching of citrus

4) Reduced leaf size and shortening of internodes in brinjal and mango called as **little leaf.**



Cupper

Functions

- Similar to other micronutrient cations, copper is absorbed by plant roots as Cu^{2+}.
- Concentration of Cu^{2+} in copper sufficient plants is from 5 to 30 ppm and toxicity occurs between 20 and 100 ppm.
- Cu^{2+} is a component of large number of proteins and enzymes like plastocyanin, SOD, Diamine oxidase, polyphenol oxidase, Ascorbate oxidase.
- Important in imparting disease resistance.
- Enhances fertility of male flowers.

Deficiency symptoms

- Plants having a copper content of less than 5 ppm are regarded as Cu deficient.
- Male flowers' sterility, delayed flowering and senescence are the most important effects of Cu deficiency.
- Chlorosis of the younger shoot tissue, white tips, reclamation disease,
- necrosis, leaf distortion and die back are characteristics of Cu deficiency.
- Necrosis of apical meristem results in elongation of shoot in cereals and auxiliary shoots in dicots.
- The shoot apex may cease to grow, resulting in the development of several auxiliary bunds.
- In cereals symptoms appear as bleaching and withering of young leaves.
- Exanthema and dieback in citrus which manifests as dark brown spots on the leaves, terminal twigs and fruits.
- Yellowish brown blotches on the leaf particularly in legumes.

- Tip drying and bluish green leaf tips are the symptoms in rice.
- Empty glumes in wheat.
- Total amino nitrogen accumulates in plants.

Iron

Functions

- Iron is taken up in Fe2+ form by plants. Its concentration in the range of 100 – 500 ppm in mature leaf tissue is regarded as sufficient for crop production. Variable valency of iron assigns it a role in biological redox systems.
- Iron is a constituent of two groups of proteins viz., a) Heme proteins containing Fe – porphyrin complex. eg., peroxidase, leghaemoglobin.
- Fe-S proteins in which Fe is coordinated with thiol group Eg : Ferredoxin.
- It activates a number of enzymes including aminolevolinic acid synthetase and Coproporphyrinogen oxidase.
- It plays an essential role in the nucleic acid metabolism.
- It is necessary for synthesis and maintenance of chlorophyll in plants.
- It is structural constituent of pigments in micro-organisms; the black pigment in Aspergillus niger contains iron)

Deficiency :

- The critical limit of iron in plant is 30 ppm, the sufficiency range being 50 and 250 ppm.

- It has been established that Fe2+ content of the plant rather than total Fe content resolves Fe def.
- Deficiency of Fe results in interveinal chlorosis appearing first on the younger leaves with leaf margins and veins remaining green. Plants having less than 50 ppm of Fe are usually classified as iron deficient.
- In later stage burning of the chlorotic leaves start from the tips and margin, spread inwards.
- The chlorotic leaves may become white and the leaf tissues devoid of chlorophyll die.
- Leaves with large necrotic areas fall off and twigs defoliate.
- In mild cases, mottled pattern may be seen with primary and secondary
- veins retaining their green color.
- In graminaceous crops, chlorosis consists of alternate strips with green veins and yellow interveinal tissues.
- In case of barley, maize and jowar, leaves show reddish brown spots on leaves away from the base on margin.
- Under conditions of severe deficiency, growth cessation occurs with the whole plant turning necrotic.

Manganese

Functions :

- Healthy Mn sufficient mature plants contain 20 to 300 ppm of Mn. It is a transitional metal, present in plants in Mn2+ form. Because of its variable valence, Mn plays an important role in the photosynthesis and detoxification of superoxide free radicals.

- Mn is an integral component of the water splitting enzyme associated with photosystem II. Because of this role, Mn deficiency is associated with adverse effects on photosynthesis and O2 evolution.
- It is a constituent of superoxide dismutase (Mn-SOD). Mn SOD, present in mitochondria protects cells against the deleterious effects of superoxide free radicals.
- Mn has a role in TCA cycle in oxidative and non oxidative decarboxylation reactions with Nicotine Adenine Diamide (NAD) or Malic dehydrogenase enzyme catalyzing the reaction.

Deficiency symptoms :

- Mn deficient plants contain less than 25 ppm Mn.
- Deficiency symptoms of Mn are more severe on middle leaves than on the younger ones because Mn is preferentially translocated to the younger tissues. Interveinal chlorosis in dicotyledons is characterized by the appearance of chlorotic and necrotic spots in the interveinal areas. In monocotyledonous plants like cereals, Mn deficiency symptoms appear as greenish grey spots, fleeks and stripes more on the basal leaves (Grey speck). Chlorotic leaf areas soon become necrotic and turn red, reddish brown or brown. Symptoms of Mn deficiency are popularly known as Grey speck of Oats, Speckled yellow of sugar beet, Marsh spot of peas, Pahala blight of sugar cane, Frenching of tung grass

Boron

Functions of boron :

- Boron is absorbed by plants as boric acid. However, it can also be absorbed in anionic form viz., dihydrogen borate ($H_2BO_3^-$), monohydrogen borate (HBO_3^{2-}) under acidic conditions and borate BO_3^{3-} under high pH condition.
- Normal boron sufficiency in plants is between 10 and 200 ppm.
- Boron is neither a constituent of enzymes nor it activates any of the enzymes.
- Most important property of boron (H_3BO_3) is to form stable complexes with organic compounds with cis - diol configuration.
- It is responsible for cell wall formation and stabilization, lignification and xylem differentiation. As a consequence, B deficiency causes changes in chemical composition and ultra structure of cell wall, accumulation of toxic phenols, inhibition of lignin synthesis and a decrease in the production of indole acetic acid (IAA). Decrease in IAA is responsible for the induction of Ca deficiency.
- It imparts drought tolerance to the crops.
- Plays a role in pollen germination and pollen tube growth.
- It facilitates ion uptake by way of increasing the activities of plasma membrane bound H^+ - ATPase.
- It facilitates the transport of K in guard cells as well as stomatal opening.

Deficiency symptoms

- Plants having B concentration in the order of 5 to 30 ppm are suspected to be boron deficient. Critical deficiency range of B varies from 5 to 10 ppm in graminae plants and 20 to 70 ppm in dicotyledons.
- Boron deficiency symptoms are conspicuous on the terminal buds or the youngest leaves; which become discolored and may die under acute deficiency.
- Internodes become shorter and give appearance of a bush or rosette.
- Increased diameter of stem and petiole gives rise to the typical cracked stem of celery.
- Specific names given to B deficiency in different crops are
- Heart rot of sugar beet.
- Browning or hollow stem of cauliflower.

- Top sickness of tobacco
- Internal cork of apple.

Molybdenum

Functions

- Mo is a constituent of nitrate reductase.
- Activates several enzymes like catalase, peroxidase and polyphenol oxidase.
- Inhibits acid phosphatase.
- Required by N fixing organisms like Azotobacter, clostridium, Nostoc, Anabaena.
- Being a constituent of the Hydrogenase enzyme, helps in enzymatic transfer of e- for reduction of N N bonds.
- Deficiency of Mo results in accumulation of nitrates.
- Involved in carbohydrate metabolism and sugar formation.

Deficiency:

- In most plants with reticulate venation, the first effect of Mo deficiency appears as chlorotic mottling between the veins.
- Brassica crops are very susceptible to Mo deficiency, the symptoms developing in 3-4 week old plants.
- Tomato, lettuce, spinach, beet root and Brassica speces especially cauliflower, broccoli and rape seed are very sensitive to restricted Mo supply.

- Legumes develop symptoms which resemble N deficiency.
- Grasses seem to have low Mo requirement.
- Citrus plants develop ‘yellow spot’.
- Cauliflower exhibits whiptail (leaves get twisted elongated)
- Cabbage shows cupping, veins become purple, leaves become necrotic and malformed along the margins.
- Tomato – chlorotic mottling – old leaves roll inwards along leaf margin.
- In rice, slight chlorosis between the vein in the middle of the upper and middle leaves and extending across the width.

Chlorine

Functions

- Chlorine has been shown to be involved in the oxygen evolution in photosynthetic reactions.
- Claimed to be involved in photophosphorylation.
- In microorganisms, chlorine containing metabolically active compounds like chlorometabolites were found.
- In higher plants, chlorides largely accumulate in free ionic form in cell vacuoles.

Deficiency symptoms

- Common symptoms are wilted appearance of the foliage and stuffy roots with laterals showing branching.
- Tomato leaves show chlorotic mottling, bronzing and tissue necrosis.

Movement of ions soils to roots - Mass flow, diffusion, root interception and contact exchange

Movement of ions from soils to roots-

For the ions to be absorbed by plants roots, they must come in contact with the root surface. This generally takes place by three ways in which the nutrient ions in soil may reach the root surface

1. Movement of ions by mass movement in the soil solution – Mass flow.
2. Diffusion of ions in the soil solution – Diffusion.
3. Root interception and contact exchange.

I. **Mass flow**:

Movement of ions from the soil solution to the surface of roots is accomplished largely by mass flow and diffusion. Mass flow, a convective process occurs when plant nutrient ions and other dissolved substances are transported in the flow of water to the root in en mass that results from transpirational water uptake by the root. This depends on the rate of water flow or the water consumption of plants. Mass flow supplies an over abundance of calcium, magnesium is many soils and the most mobile nutrients such as N and S.

Factors affecting mass flow As mass flow involves nutrient movement with water, both the amount of water and volume of soil it comes from, affect the mass flow.

1) **Soil moisture content**: In dry soil, no mass flow of nutrients occurs because there is no water to carry them to the plant roots. .
2) **Soil temperature**: Low temperature reduces transpiration and evaporation; resultantly reduced water flux occurs across the roots.
3) **Size of the root system**: affects the water uptake and consequential mass flow. Root density, however is much less critical for nutrient supply by mass flow than for root interception and diffusion.

II. Diffusion:

Most of the phosphorus, potassium (relatively immobile) and micronutrients (present in small quantities), move to root by diffusion. Diffusion occurs when an ion moves from an area of high concentration to one of low concentration by random thermal motion. As plant roots absorb nutrients from the surrounding soil solution, a diffusion gradient is set up. A high root absorbing power results in a high diffusion gradient favouring ion transport. The three principal factors influencing the movement of nutrients into the roots are the diffusion coefficient, concentration of the nutrient in soil solution and the buffering capacity of the solid phase to release nutrients into the soil solutions.

Soil moisture is a major factor that affects the relative significance of the mass flow and diffusion. Diffusion becomes progressively less important as the moisture content decreases.

The amount of nutrient ion diffusing across a unit area in unit time (F) with a concentration gradient, dc/dx is given for steady state diffusion by

Fick's first law of diffusion $F = -D\ (dc/dx)$

D is the diffusion coefficient in the soil with units cm^2/s

The minus sign indicates movement from higher to lower concentration.

Factors affecting diffusion

1. **Soil water:** The higher the moisture content, higher will be the diffusion coefficient, until the moisture content reaches saturation.
2. **Soil compaction:** Incremental increase in the soil compaction at the same moisture content leads to the exclusion of air; soil particles come closer, the continuity of moisture flows increases, path to be traversed by the ion by diffusion becomes less tortuous and resultantly, the diffusion coefficient exhibits an increase.
3. **Temperature:** The rate of chemical reaction doubles for every 10^oC rise in temperature. The increase in temperature increases the effective diffusion coefficient of a nutrient ion.
4. **Chemical amendments**: Chemical treatments modify the concentration of the nutrient ions in soil solution as given below
    - Amelioration of soil acidity through liming raises the pH of the soil. Thus, diffusion coefficient of cations decreases and anion increases as a result of liming.
    - Application of gypsum to a sodic soil reduces the soil pH, as a result of which diffusion coefficient raises.
    - Organic manures act as the store house of nutrients. In addition, they release low molecular

weight organic substances which have the ability to form complexes with cations. This increases the diffusion coefficient of nutrients.

III. Root interception and ion exchange: Jenny and Overstreet (1939) propounded the ‘theory of contact exchange’. Theory of contact exchange rests on the concept of overlapping oscillation spaces of adsorbed ions, or redistribution within intermingling electric double layers. Contact exchange as a mechanism for nutrient movement could be pictured as

$$\text{Clay}\quad M^{+} \quad + \quad H^{+}\text{ - Root} \quad \rightarrow \text{Clay - }H^{+} \quad + \quad M^{+} \quad \text{Root}$$

and modelled as

$$\text{Clay}\quad M+ \quad H+ \quad \text{Root}$$

Cation exchange theory on further refining gave rise to the concept of ‘root interception’ a term coined by Stanley A Barber, which is used to describe the soil nutrients at the root surface that do not have to move to the interface to be positionally available for absorption, but are approached by the root itself in the soil.

As the root system develops and exploits the soil more completely, soil solution and soil surfaces retaining the adsorbed ions are exposed to the root mass and absorption of these ions by the contact exchange mechanism is accomplished. The quantity of nutrients that can come in direct contact with the plant roots is the amount in volume of soil equal to the volume of roots. It can be assumed that roots usually occupy 1 % or less of the soil. It is estimated that roots would contact a maximum of 3 % of the available nutrients in the soil.

It has been observed that plant roots also possess the cation exchange property, ranging from 10 to 100 Cmol/ kg roots. This property could be due to the –COOH groups of pectic substances of cell wall. Legumes have high root CEC and absorb more divalent cations, monocots have low root CEC and absorb more of monovalent cations like K^{+}. Ions attached to the surface of roots may exchange with those held on the surface of clays and organic colliods because of the contact between roots and soil particles. The mucilaginous gel around root surface could serve as contact complex. The presence of mycorrhiza, a symbiotic association between fungi and the roots of plants, enhances the uptake of nutrients particularly phosphorus.

Factors influencing the content of nitrogen in soil

The ultimate source of nitrogen used by the plants is the inert gas nitrogen, which constitutes about 78 % (by volume) of the earth's atmosphere. Among all the essential nutrients, nitrogen is the extensively studied one and still receiving much attention.

The ploughed layer of majority of cultivated soils contains about 0.02 – 0.04 % nitrogen. Indian soils have very low content because of low organic matter accumulation due to tropical climate. Soils developed under cool humid climate have higher N content than those formed under dry climate. On an average, black soils have more nitrogen content (0.08%) than red soils (0.03%).

Factors influencing the content of N in soils

a) **Climate**

   i) Temperature: Lower the temperature higher is the N content due to more organic matter addition and slow rate of decomposition.
   ii) Water supply: Soil N content increases with water supply up to field capacity.

b) **Effect of cultivation**: N content decreases with cultivation due to organic matter loss through decomposition.

c) **Soil texture**: Finer the texture, higher is the N content.

d) **Depth in the profile**: Surface soil has more N content than deeper soils.

Forms of soil nitrogen:

The total nitrogen content of soils ranges from less than 0.02 % in sub soils to more than 2.5 % in peat soils. The N present in soil can generally be classed as inorganic (around 2 %) and organic (around 98 %).

1. **Inorganic nitrogen compounds**: The inorganic forms of soil nitrogen include ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO) nitrous oxide (N_2O) and elemental nitrogen. NH_4^+, NO_3^- and NO_2^- are important in soil fertility and represent 2 to 5 % of total

nitrogen.

2. **Organic nitrogen compounds** : occur as consolidated amino acids or proteins, free amino acids, amino sugars and other unidentified compounds like materials that result from the reaction of NH_4^+ with lignin, polymerisation of quinones and nitrogen compounds, the condensation of sugars and amines. Bound amino acids are to the extent of 20-40 %, amino sugars (hexosamines) 5 to 10 %, purine and pyrimidine derivatives 1 % or less.

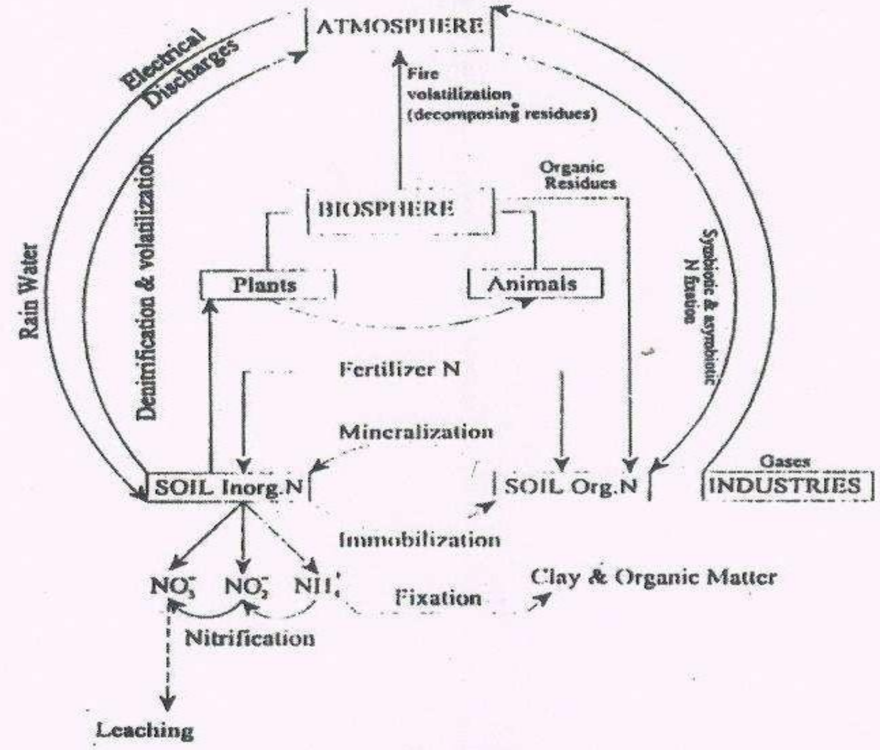


Figure 1. The nitrogen cycle in the environment
(*Source*: Srivastava and Singh, 1996)

N transformations in soil: Plants absorb most of the N in the NH_4^+ and NO_3^- forms. Nitrate is the dominant source as its concentration is higher than NH_4^+ and it is free to move to the roots. Potatoes, sugarbeet, pine apple, prefer both the forms; tomatoes, celery, bush beans, prefer NO_3^- , rice and blue berries prefer NH_4^+.

NO_3^- -N uptake is usually high and is favoured by low pH conditions.

NH_4^+ -N is less subjected to losses by leaching and denitrification. NH_4^+ uptake is best at neutral pH values. When the plants are supplied with NH_4^+-N, it leads to acidity in the soil.

Mineralization of N compounds: N mineralization is simply the conversion of organic nitrogen to mineral form (NH_4^+, NO_3^-, and NO_2^-). When organic residues having a C: N ratio wider than 30 are added to the soil, immobilisation of nitrogen takes place. If C:N ratio is narrow i.e., less than 20 (for legume residues), mineralisation is the result. It takes place essentially by three steps.

1. Aminisation 2. Ammonification 3. Nitrification.

1. **Aminisation**: Heterotrophic soil microbes, mostly, bacteria like *Pseudomonas* and *Bacillus* are believed to dominate in the break down of proteins in neutral and alkaline soils. Under acidic conditions fungi prevail. In this step hydrolytic decomposition of proteins and release of amines and amino acids takes place.

$$\text{Proteins} \;€\; R\text{-}NH_2 + CO_2 + \text{Energy} + \text{other products.}$$

2. **Ammonification**: The amines and amino acids so released are further utilized by still other groups of heterotrophs with the release of ammoniacal compounds. The step is termed as ammonification.

$$R\text{-}NH_2 + HOH \;€\; NH_3 + R - OH + \text{Energy.}$$

$$NH_3 + H_2O \;€\; NH^{+} + OH^{-}$$

The ammonium thus formed may be nitrified to nitrite and nitrate which are used by plants.

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Fate of released ammonium in the soil

1. It may be converted to nitrites and nitrates by the process of nitrification.
2. It may be absorbed directly by higher plants.
3. It may be utilized by heterotrophic organisms in further decomposing organic carbon residues.
4. It may be fixed in biologically unavailable form in the lattice of certain expanding type clay minerals.
5. It could be released back to the atmosphere through volatilization

Ammonium fixation

In agricultural soils, 5 – 20 % of the total nitrogen is found as fixed ammonium ion, with an average of 10 %. When ammonium containing or ammonium forming fertilizers are added to the soil, most of ammonium gets adsorbed on the cation exchange sites, but a part of it is susceptible to strong adsorption in the interlayer spaces of some 2:1 layer silicate clay minerals with an expanding lattice. The order of fixation is as follows: vermiculite > fine grained mica> smectites.

The ammonium ion has an ionic diameter 2.96 ^{o}A, which is close to the 2.8 ^{o}A diameter of inter lattice spaces in 2:1 type clay minerals. Fixed ammonium is not easily available for plants and microbes. It comes out by a replacement of NH^{+} for inter layer cations in the expanded lattices of clay minerals. The fixed ammonium can be replaced by cations that expand the lattice like Ca^{2+}, Mg^{2+}, Na^{+}.

The presence of K^{+} (ionic diameter of 2.68 ^{0}A) will often restrict NH^{+} fixation since this ion can also fill fixation sites. Consequently it has been suggested that K fertilization prior to NH^{+} application is a practical way of reducing NH^{+} fixation.

Ammonium can also be chemically fixed or bound by the organic matter. The reactions take place most readily in the presence of oxygen and at high soil pH. In organic soils with high fixing capacity, the reaction could result in a serious loss of available nitrogen and would dictate the use of fertilizers other than those that supply $NH4^{+,}$ however, the fixed NH^{+} will be slowly released by mineralization.

Factors affecting ammonium fixation

1. **Type and amount of clay**: NH_4^+ fixation increases with increase in the content particularly 2:1 type of clay minerals like vermiculite, fine grained mica and smectite.

2. **Moisture content of the soil**: The moisture content and temperature of the soil will affect the fixation of $NH_4^{+.}$ Freezing and drying increases the fixation. Alternate cycles of wetting and drying; freezing and thawing are believed to contribute to the stability of recently fixed NH_4^+

3. Amount of K^+ : The presence of K^+ will restrict NH_4^+ fixation since K^+ also fills the fixation sites.

4. Depth of the soil: Fixation of NH_4^+ is generally higher in sub soil than surface soil due to higher clay content and lower rate of nitrification.

5. Organic matter content: Higher the organic matter content more is the NH_4^+ fixation.

6. Population of nitrifying bacteria: Nitrifying bacteria oxidize NH_4^+ to nitrite and nitrates thus reducing the chances for NH_4^+ fixation.

Nitrification – Factors affecting nitrification – Fate of nitrate nitrogen – Leaching losses of nitrate nitrogen – Denitrification – Nitrification inhibitors – Immobilisation

Nitrification: The biological oxidation of NH^+ released by the process of ammonification to nitrate is known as nitrification. This process is carried out by nitrifying bacteria referred to as nitrifies. It is a two step process in which NH_4^+ is first converted to nitrite (NO_3^-) and then to nitrate (NO_3^-). Conversion to nitrite is brought about largely by a group of obligate autotrophic bacteria known as *Nitrosomonas* as

$$2\ NH4^{+} + 3\ O\ \text{€}\ 2\ NO2^{-} + 2\ H2\ O + 4H2^{+}$$

The conversion from nitrite to nitrate is affected by *Nitrobacter* as follows :

$$2\ NO2^{-} + O2\ \text{€}\ 2\ NO3^{-}$$

Factors affecting nitrification

i)**Supply of the ammonium ion**: Because the substrate for the nitrifying bacteria is the ammonium ion, a supply of this ion is the first requirement for nitrification.

ii)**Population of nitrifying organisms**: Under similar conditions of temperature, moisture and added ammonia, the nitrification is greatly influenced by population of nitrifying bacteria.

iii)**Soil reaction**: Nitrification takes place between pH of 5.5 to 10.0, with an optimum around 8.5.

iv)**Soil aeration**: The nitrifying bacteria are anaerobes and hence require sufficient oxygen supply.

v)**Soil moisture**: The rate at which nitrification proceeds in a soil is governed to a marked extent by the water content being retarded by both very low or very high moisture content.

vi) **Temperature**:Very low nearer freezing and increases rapidly up to 35^oC.

vii) **C : N ratio**: when organic residues with wide C : N ratio are added, general purpose decay organisms are dominant and nitrifiers become inactive.

viii) **Pesticides**: Nitrifying organisms are quite sensitive to some pesticides.

Fate of nitrate nitrogen

Nitrate supplied in commercial fertilizers or produced by nitrification of ammonium may be:

Absorbed by the plants.

Utilised by soil microorganisms.

Lost through excess water by leaching because of its higobility.

Escapes from soil in volatile condition through nitrate reduction referred to as denitrification.

Leaching losses of nitrate nitrogen:

Leaching loss of nitrogen from the soil is a loss from the soil-plant system and causes lower efficiency of applied nitrogen. It may vary from 2 to 50 % of applied N. Of the total leaching loss, more than 90 % is in the form of NO $^-$ as mostly nitrate ions are present in soil solution because of the reason that the anion exchange capacity of the soil is much less than cation exchange capacity. Therefore, its movement is related to the movement of water in the soil. The magnitude of leaching loss of nitrogen depends on soil texture, hydrological condition, water table depth, permeability and hydraulic conductivity of soil. Leaching loss can be reduced by increasing water holding capacity through organic matter addition, split application of fertilizer N, controlled irrigation and by using nitrification inhibitors like N – serve, slow release N fertilizers like neem coated urea, sulphur coated urea.

Denitrification :

Denitrification is a process limited to anoxic soils in which bacterial reduction of NO $^-$ and NO $^-$ takes place leading to the release of NO, N O and N gases. When soils become water logged, oxygen is excluded and anaerobic decomposition takes place. Some anaerobic organisms have the ability to obtain their oxygen from nitrates and nitrites with the accompanying release of nitrous oxide and nitrogen. The most probable biochemical pathway leading to these losses is indicated as

$$\begin{array}{ccccccccc} & +\,4H^+ & & & & & & & \\ 2\,NO_3^- & & 2\,NO_2^- & & 2\,NO & & N_2O & & N_2 \\ & -2(O) & & -2(O) & & -2(O) & & -O & \end{array}$$

Facultative anaerobic bacteria belonging to the genera *Pseudomonas*, *Bacillus denitrificans* and *Paracoccus* are responsible for this. Autotrophs like *Thiobacillus denitrificans* also brings about denitrification.

Nitrification inhibitors: Several products have been developed with the purpose of slowing the release and/or nitrification of applied N to synchronise the supply of N with the crop demand and consequently decrease nitrogen losses via leaching and / or denitrification. These chemicals restrict the growth of *Nitrosomonas* and keep nitrogen in NH_4^+ form.

Natural nitrification inhibitors Neem cake (*Azadiracta indica*) Karanj cake (*Pongamia glabra*) Neem oil and nimin

Chemical nitrification inhibitors

N - serve or nitrapyrin (2 chloro – 6 tri chloromethyl pyridine) DCD (Dicyandiamide)
AM (2 amino, 4 chloromethyl pyrimidine)
ATC (4-amino 1,2, 4 triazole) Sulphathiozole
Thiourea Hydroquinone
Calcium carbide (CaC_2)
Phenyl phosphorodiamidate (PPD)

However, in India the use of such chemicals to retard nitrification is limited due to the high costs involved.

Nitrogen immobilization

Immobilisation of nitrogen is the reverse of mineralisation and it occurs when large quantities of low nitrogen crop residues with wide C:N ratio (>30:1) such as coconut coir or cereal straw begin decomposing in soil, the high amounts of carbohydrates in such residues cause the microbial population to build up quickly. As new cells are formed, nitrogen and other essential elements from soil are used to build protoplasm. This leads to a decrease in the levels of inorganic nitrogen for crops. A shortage of nitrogen can be avoided in such situations by supplying enough fertilizer nitrogen to compensate for immobilization and to meet the crop requirements. This lockup of inorganic N of soil is temporary and slowly will be released after mineralization.

Factors affecting phosphate fixation in soil

Factors affecting P fixation in soils

1. **Clay minerals**: The main seat of P fixation in soils rests on the clay fraction. The more the surface area exposed with a given type of clay, the greater is the tendency to retain phosphorus.
2. **Type of clay**: Phosphorus is retained to a greater extent by 1:1 than by 2:1 clays. Soils high in kaolinitic clay will fix larger quantities of added P due to more AEC.

3. **Hydrous metal oxides of iron and aluminium**: In soils with significant amounts of iron and aluminium oxides, the P fixing capacity is larger.
4. **Amorphous colloids**: In Andisols, due to the presence of large quantities of amorphous colloids like allophanes with large negative charges which are balanced by aluminium cations, the phosphate becomes fixed to these aluminium ions.
5. **Calcium carbonate**: Calcium carbonate precipitates phosphates to form insoluble apatites. The activity of P will be lower in those soils that have a high Ca^{2+} activity.
6. **Soil pH** : Adsorption of P by iron and aluminium oxides declines with increasing pH.
7. **Organic matter**: High organic matter content decreases P fixation.
8. **Temperature**: The rise in temperature generally enhances P fixation.
9. **Over liming**: Over liming increases P fixation by forming more insoluble Ca-P compounds.

Methods to reduce P fixation

1. **Organic matter addition**: Incorporation of organic residues into soil influences the reactions of phosphates and its availability to plants. Organic matter counteracts the effect of $CaCO_3$. It also reduces P sorption by soil. Addition of organic matter also increases P concentration in soil solution through mineralization of organic P and solubilisation of native soil P compounds. This effect is more pronounced at higher moisture level. During decomposition of organic matter various organic acids are produced which solubilize the phosphates and other P bearing minerals and thereby lower the P – fixation.

   The reason is

   1. By formation of phospho - humic complexes that are easily assimilated by plants.

      Through the mobilisation of the phosphate by humate ion by anion exchange

   2. By forming a coating on sesqui oxide particles by humus as a protective cover which otherwise fix P.

2. Placement of fertilizers: The finer the soil texture, the greater is the retention of added P due to increased speed of reaction with surface area of contact. If finely divided fertilizer P is added to a soil by applying through broadcast the phosphate is exposed to a greater amount of surface, hence more fixation takes place. While band placement reduces the surface of contact between the soil and fertilizer with consequent reduction in the amount of fixation.

3. **Role of mycorrhiza** : Certain mycorrhizal fungi known as VAM colonize plant roots and through this association help the plant to absorb more P.

4. **Role of P solubilising microorganisms**: P solubilising bacteria like *Bacillus megatherium* and *Pseudomonas striatus*; or fungal species namely *Aspergillus awamori* are reported to enhance the availability of fixed P and reported to add 30 – 35 kg P_2O_5 ha^{-1} under ideal conditions.

5. **Liming of acid soils**: About one- third of Indian soils are acidic in reaction. The beneficial effect of liming of these acid soils is due to the release of fixed P that was held with iron, aluminium oxides &hydroxides.

Quantity– Intensity relationships Schofield (1955) divided the measurements

i) **Intensity of supply**: Which indicates the soil solution phosphate and is measured by phosphate potential.

ii) **Quantity factor**: rich indicates the total quantity of P in the soil. This pool supplies P to the soil solution pool (intensity) when P is taken up by plants.

In a limited range of P concentration where Q/I relationship is linear, the slope of the curve is given by which is referred to as phosphate buffering capacity or simply capacity, which indicates the resistance of soil to a depletion in quantity of P. For a given value of intensity, the quantity values are higher for fine textured soils than coarse textured soils. Availability of P to plants is controlled by the mutual interplay of the three factors viz., quantity, intensity and PBC. Hence, in clay soils depletion is less than sands, hence can supply P to the crops for longer period.

Functions of phosphorus in plants:

Phosphorus is the second most abundant mineral in human body making up for more than 20 % of body minerals. It is largely absorbed by the plant roots as dihydrogen orthophosphate ion ($H_2PO_4^-$). In normal P sufficient plants, P content varies from 0.1 to 0.4 per cent by weight.

The following are the functions of phosphorus in plant system

1. Constituent of nucleoproteins, phytins and phospholipids.
2. Essential constituent of number of enzymes -important in energy transfer.
3. Essential for cell division and development.
4. Stimulates root development and growth.
5. Responsible for early establishment of seedlings.
6. Strengthens the straw and decreases lodging.
7. Brings about early maturity.
8. Counteracts the effect of excessive nitrogen.
9. Increases grain to straw ratio.
10. Improves the quality of food grain.
11. Increases rhizobial activity, increases the formation of root nodules thus helping in more N - fixation.

Deficiency symptoms: In general, plants having less than 0.1 % phosphorus are designated as P-deficient. Because of its faster mobility in plants, P gets translocated from older tissues to the meristematic tissue. Therefore, deficiency symptoms of P first appear on the older leaves.

P deficiency results in

The production of dark green color leaves.

Severe restriction of root growth.

Thin, erect and spindly plants with sparse and restricted foliage.

suppressed lateral bud production.

bluish green foliage, and under continued deficiency the older leaves become bronzed or develop reddish purple tip or leaf margins.

Toxicity symptoms

Excess of P causes trace element deficiency particularly Fe and Zn.

Correction of deficiency

Generally, P is applied as a basal application by band placement. The following are the phosphatic fertilizers.

1. Single Super Phosphate (SSP) contains 16 to 22% P_2O_5
2. Rock phosphate contains 30-38 % P_2O_5
3. Triple Super Phosphate contains 46 % P_2O_5
4. Diammonium phosphate contains 46 % P_2O_5
5. Monoammonium phosphate contains 52 % P_2O_5
6. Basic slag contains 10-20 % P_2O_5

Factors affecting potassium fixation – Quantity and intensity parameters – Luxury consumption – Functions and deficiency symptoms – corrective measures

Factors affecting K-fixation

1. Clay minerals: K fixation is controlled mainly by clay minerals, with both their quantity and nature being important. Illite, weathered mica, vermiculite take part in K fixation but 1:1 type of clays such as kaolinite do not fix potassium.

2. Soil reaction: K fixation capacity can be reduced by the presence of Al^{3+} and Al-hydroxide cations.

3. Cation Exchange Capacity (CEC): Fine textured soils have a higher CEC and hold more exchangeable K.

4. Concentrations of added K: Increasing the concentration of K^+ in soils with high fixing capacity encourages greater fixation.

5. Wetting and drying: Soils with high exchangeable K^+ on drying will result in fixation due to air drying.
6. Freezing and thawing: of moist soils may release fixed K.
7. Sub soil K and rooting depth: Exchangeable K varies with depth
8. Soil temperature: Higher temperature favors dehydration and

9.Ca and Mg (exchangeable cations): The size of K^+ and other ions that would replace K is important in K fixation. The cations of smaller size of the hydrated ions can easily enter into clay lattices and replace some of the fixed potassium.

Quantity and intensity parameters

The concept of intensity, quantity and buffering power proposed by Beckette (1964) are useful in measuring the potassium supplying power of soils.

Intensity factor is a measure of K in soil solution that is immediately available for absorption by plants. Since this absorption is influenced by the activity of other cations like Ca^{2+} and Mg^{2+} in the soil solution, the potassium activity ratio (AR^k) is used in place of K concentration alone to indicate the intensity factor.

$$AR^k = \frac{[\,K^+\,]}{[\,Ca^{2+} + Mg^{2+}\,]}$$

Quantity factor is a measure of the capacity of the soil to maintain the level of K in soil solution over a long period or over the duration of crop growth. The capacity is mainly due to the exchangeable K

The slope of the curve indicates the potential buffering capacity, which indicates how the K level in the soil solution (intensity) varies with the amount of labile form (quantity)

$$PBC = \frac{\Delta Q}{\Delta I}$$

The wider the ratio, the more buffered is the soil. Soil having smectitic clay have more PBC, than having kaolinite.

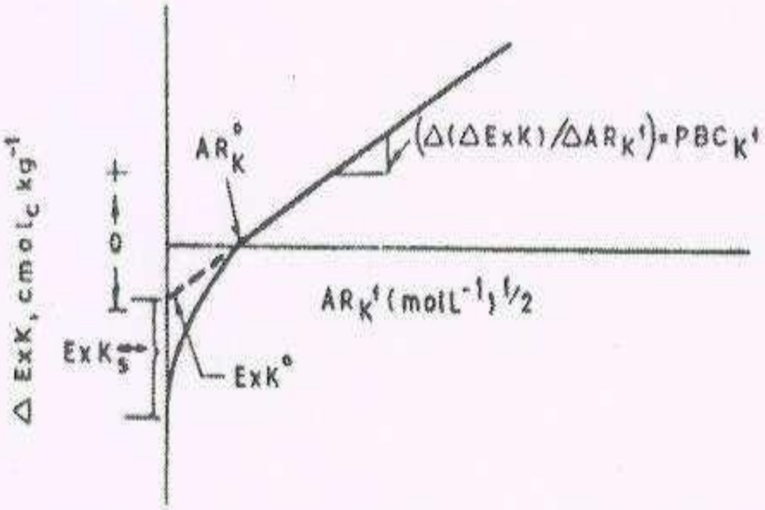
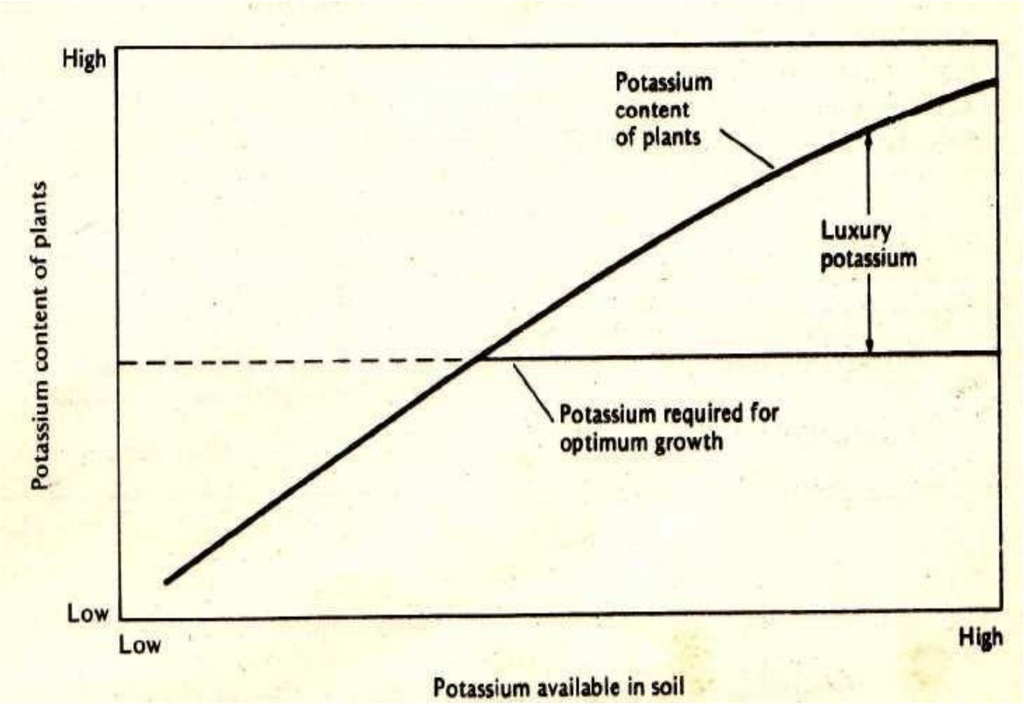


Figure 3. A typical quantity/intensity (Q/I) relations (adapted from Evangelou, 1994)

Luxury consumption: Some crops tend to absorb and accumulate potassium for in excess of their needs if it is present in sufficiently large quantities in the soil. This tendency is termed luxury consumption because the excess K absorbed does not increase crop yields to any appreciable extent. Wasteful luxury consumption occurs especially with forage crops.



Functions: K is absorbed by the plant as K^+. Its concentration in healthy tissue varies from 1-5 %. Potassium is a unique element that plants can accumulate it in abundant amounts without exhibiting any toxicity symptoms. This behaviour is referred to as luxury consumption. Potassium plays a regulatory role in plant metabolism. Potassium is not a component of any organic compound in plants.

- It regulates the opening and closing of stomata.
- Plays a major role in transport of water and nutrients throughout the plant in xylem.
- It improves drought tolerance.
- Neutralizes organic anions and other compounds and maintains the pH of cytoplasm in the range of 7-8.
- Activates > 60 enzymes, including starch synthetase, K is responsible for the activation of nitrate reductase enzyme.
- Enhances crop quality, shelf life of fruits and vegetables.
- Reduces lodging of crops, enhances winter hardiness.
- Imparts disease resistance.

Deficiency symptoms

1. Potassium deficiency does not manifest immediately in the form of visible symptoms.

First growth rate decreases and later deficiency symptoms appear.

2. Deficiency symptoms first develop on the older leaves.

3. Chlorosis along the margins followed by scorching and browning of tips of older leaves which gradually progresses inwards giving burning appearance.

4. Slow and stunted growth of the plant and crop lodging.

5. Shrivelled fruits and seeds.

6. Reduced crop yields without the appearance of definite symptoms; the phenomenon is called hidden hunger.

7. Decrease in resistance to certain plant diseases

8. Decrease in the quality of fruits and vegetables.

9. Potassium deficiency disturbs the overall physiological activity within the plant system by altering the activities of enzymes like invertase, catalase in crops like sugarcane.

Correction measures

Potassium chloride or muriate of potash constitutes 99% of usage of K fertilizer and potassium sulphate accounts for 1%. Muriate of potash contains 60% K_2O or 50% K and sulphate of potash contains 50 % K_2O or 41.5% K.

Some crops are sensitive to high amounts of potassium chloride. These include tobacco, grapes, cotton, fruit trees, sugarcane, potatoes, tomatoes, straw berries, onion and cucumber. Oil palm and coconut on the contrary appear to be chloride loving crops.

Generally, potassic fertilizers are applied as basal dose, but for light textured soils, split application is advocated. In Andhra Pradesh split application of N and K are recommended for light soils.

Potassium nitrate containing 44% K_2O (37% K) and 13% N is preferred for spraying on fruit trees and horticultural crops. Spraying of KNO_3 during winters (*rabi* season) to impart cold hardiness is also in practice by the farmers in Andhra Pradesh.

Predisposing factors for occurrence of micronutrient deficiencies in soil and plants

i) **Parent material**: The soils whose parent material originally contain low amounts of micronutrients are most likely to show micronutrient deficiency under leaching and intensive cropping.

ii) **Soil pH:** Acid soil conditions are most conducive for Mo deficiency. Similarly, high pH soils such as sodic soils show Zn, Fe, Mn and Cu deficiency. Over liming of acid soils also causes deficiency of micronutrient cations. In acid sulfate soils micronutrient toxicity limits crop growth.

iii) **Land leveling and shaping:** Land leveling and shaping removes the fertile top soil in which micronutrients are concentrated.

iv) **High yielding varieties:** HYV require more nutrients depleting the nutrients from soil causing their deficiencies.

v) **Imbalanced nutrient application**: High doses of macronutrient application induces micronutrient deficiencies.

vi) **Soil conditions**: Water logged condition reduce the availability of Zn and Cu and increase availability of Fe and Mn.

vii) **Organic matter:** Organic compounds like humic and fulvic acid form organo - metallic complexes held as insoluble complexes. But some organic ligands can keep micro nutrient cations as soluble chelates and those are plant available.

viii) **$CaCO_3$:** More $CaCO_3$ leads to less availability of Fe, Mn, Zn, and Cu; and increases Mo availability.

ix) **Soil texture:** Boron is available in more amounts in coarse fraction, but fixed in fine textured soils.

x) **Clay content:** Montmorillonite adsorbs more Zn and Cu.

xi) **Fertilizers:** Fertilizers containing macronutrients when applied to soil induce the deficiency of micronutrients. Basic nitrate salts reduce iron availability.

xii) **Interactions with macronutrients**: Interaction is defined as the influence of an element upon another in relation to crop growth. Negative interaction is observed between P and Zn leading to P induced Zn deficiency.

Soil fertility Evaluation: - Approaches – Nutrient deficiency symptoms. Soil testing – Objectives of soil testing –

Literally the word fertile means ‘bearing abundantly’ and a fertile soil is considered to be one that produces abundant crops under suitable environmental conditions.

Soil fertility: is concerned with the inherent capacity of soil to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other factors such as light, moisture, temperature and the physical condition of the soil are favourable. Soil fertility is an aspect of the soil plant relationship viz., plant growth with reference to plant nutrients available in soil.

Justus Von Liebig 1840 propounded the ‘law of Restitution’ which states that in order to maintain soil fertility nutrients removed from the soil by crops must be restored by the application of manures and fertilizers.

The assessment of nutrient supplying capacity of the soil is soil fertility evaluation. It necessitates understanding of certain major concepts having definite bearing on soil fertility.

The law of minimum was put forward by Von Liebig which envisages that if a soil contains optimum / adequate amounts of all but one nutrient element, crop growth is regulated by that single nutrient.

Approaches for soil fertility evaluation: The wide variety of diagnostic techniques used so far can be broadly grouped into

1) Soil Analysis
2) Plant Analysis
3) Biological methods.
4) Visual symptoms of nutrient deficiency or toxicity.

Soil testing and plant analysis are useful tools for making recommendations for application of fertilizers to crops. Soil testing gives a measure of the availability of nutrients to crops, plant analysis indicates the actual removal of the nutrients from the soil.

Objectives of soil testing

1. Grouping soils into classes relative to the levels of nutrients for suggesting fertilizer practices.
2. Predicting the probability of getting profitable responses.
3. Helping to evaluate soil productivity.
4. Determining specific soil conditions like alkali, salinity and acidity which limits crop yields.

Available nutrients: Plants draw their nutrients from air, water and soil. The bulk of mineral nutrients come from soil. Soil available form of nutrient is that fraction which is distributed in different discrete chemical forms, which often exist in a state of dynamic equilibrium and constitute the pool from which plants draw it. Soil available form of a nutrient is also that fraction whose variation in amount is responsible for significant changes in yield and responses. The nutrient available to biological organisms is termed as bioavailable nutrient.

Chemical methods for estimating nutrients

Soil testing includes measurement of available N, P, K, S, micronutrient, lime and gypsum requirement, besides measuring pH, EC and calcium carbonate, texture by Bouyoucos hydrometer method.

The different extractants for the available nutrients

Nutrient	Extractant
Available P	0.5 M NaH CO_3, pH 8.5 Olsen's extractant
	0.03 N NH_4F + 0.025 NHCl Bray's No.1 extratant
Available K	Neutral normal ammonium acetate
Available S	0.15 % $CaCl_2$

Available Zn, Fe, Cu, Mn	0.005 M DTPA, pH 7.3 Diethylene Triamine penta Acetate
Gypsum requirement	Schoonover method
Lime requirement	Shoemaker et al.

Rating limits of soil test values

Nutrient	Low	Medium	High
Organic carbon (%)	Below 0.5	0.5 – 0.75	Above 0.75
Avail. N (kg ha^{-1})	Below 280	280 – 560	Above 560
Avail. P (kg ha^{-1})	Below 10	10 – 24.6	Above 24.6
Avail. K (kg ha^{-1})	Below 108	108 – 280	Above 280

Avail. S (ppm)	Deficient < 10 ppm	Sufficient > 10 ppm
DTPA Zn	Deficient < 0.6 ppm	Sufficient > 0.6 ppm

Visual symptoms of nutrient deficiency or toxicity

Chemical analysis of plants may indicate the presence of more than 90 elements but 16 of them have been established to be essential for their successful growth and development; as per the criteria of essentiality. A constant balanced supply of these nutrients is essential for normal plant growth. Any imbalance among them leads to the emergence of nutritional disorders owing to their deficiencies or toxicities when an essential nutrient is in extremely short / excess supply, the plant suffers from its deficiency which is manifested in the form of specific sign termed as deficiency / toxicity symptom of the nutrient.

Visual deficiency symptoms are generally characteristic enough to permit easy identification of the deficiency of a nutrient as these appear on particular plant part at specific growth stage. The mobility of nutrients with in a plant differs markedly. Nutrients like N, P and K are readily translocated from old to young leaves under stress condition and are termed as mobile nutrients within the plant and they show up their deficiencies initially on the old leaves. The nutrients such as calcium, sulphur, boron and iron which are not retranslocated are called immobile nutrients and their deficiency symptoms first appear on young leaves. Mobility of other nutrients is intermediate.

Eg: Shortening of internodes due to Zn deficiency results primarily from impaired auxin metabolism.

The visual identification of nutrient deficiencies or toxicities is considered as a simple and inexpensive diagnostic tool in plant nutrition as it does not involve the use of any analytical equipment.

Limitations

Confident diagnosis by this approach requires much experience as the symptoms of some nutrient deficiencies are difficult to differentiate.

By the time the deficiency / toxicity symptoms appear, the crop has undergone marked set back and the ameliorative measures taken at that time may not produce optimum yields. The appearance of deficiency symptoms is an extreme limit of nutrient deficiency but even if the symptoms are not manifest, reduction in the yield of crop may occur. This condition has been termed as hidden hunger.

Plant analysis – Rapid tissue tests – DRIS – Indicator plants Plant analysis

Although plant analysis is an indirect evaluation of soil, it is a valuable supplement to soil testing. Plant analysis is useful in confirming nutrient deficiencies, toxicities or imbalances, identifying hidden hunger, evaluating fertiliser programme and determining the availability of elements. Sometimes adequate nutrients may be present in the soil, but because of other problems like soil moisture and inadequate amounts of some other nutrients, the plant availability of the nutrient in question may be constrained.

Plant analysis is based on the fact that the amount of a given element in plant is an identification of the supply of that particular nutrient and as such is directly related to the quantity in the soil.

For most diagnostic purposes, plant analyses are interpreted on the basis of critical value approach, which uses tissue nutrient concentration calibrated to coincide 90% or 95% of the maximum yield, below which the plants are considered to be deficient and above that value sufficient.

Two general types of plant analysis are in use.

1. The tissue test which is customarily made on fresh tissue in the field.
2. Total analysis performed in the laboratory with precise analytical techniques.

A. **Tissue Tests**:

Rapid tests for the determination of nutrient elements in the plant sap of fresh tissue. In these tests, the sap from ruptured cells is tested for unassimilated nitrogen, phosphorus and potassium. They are semi quantitative tests mainly intended for verifying or predicting deficiencies of N, P or K. The results are read as low, medium or high. Through the proper application of tissue testing it is possible to anticipate or forecast certain production problems which still in the field. The concentration of the nutrients in the cell sap is usually a good indication of how well the plant is supplied with nutrients at the time of testing.

(1) **Plant Part to be Selected**: In general the conductive tissue of the latest mature leaf is used for testing.

(2) **Time of Testing**: The most critical stage of growth for tissue testing is at the time of bloom or from bloom to early fruiting stage. Nitrates are usually higher in the morning than in the afternoon if the supply is short.

Test for nitrates	€	Diphenylamine
Phosphates	€	Molybdate + Stannous oxalate test
For potassium	€	Sodium cobalti nitrate

B. Total Analysis:

Total analysis is performed on the whole plant / plant parts**.** Precise analytical techniques are used for measurement of the various elements after the plant material is dried, ground and ashed and used for estimating total nutrient content.

Relative and Average Plant Nutrient Concentrations

Plant Nutrient	Average Concentration*
H	6.0%
O	45.0%
C	45.0%
N	1.5%
K	1.0%
Ca	0.5%
Mg	0.2%
P	0.1%
S	0.1%
Cl	100 ppm (0.01%)
Fe	100 ppm
B	20 ppm
Mn	50 ppm
Zn	20 ppm
Cu	6 ppm
Mo	0.1 ppm

*** Concentration expressed by weight on a dry matter basis.**

Critical Nutrient Concentration:

Critical Nutrient Concentration is the level of a nutrient below which crop yield, quality or performance is unsatisfactory. However it is difficult to choose a specific concentration.

For crops such as sugarbeet excessive concentration of N seriously affects the quality. So, CNC is maximum rather than a minimum consequently it is more realistic to use the critical nutrient range (CNR) which is defined as the range of nutrient concentration at a specified growth stage above which the crop is amply supplied and below which the crop is deficient.

Diagnosis and Recommendation Integrated System (DRIS) proposed by Beaufils (1973) which considers nutrient concentration ratios rather than individual elemental concentration for interpreting plant tissue composition. The DRIS approach measures the relative balance between nutrients by means of index values with negative values indicating insufficiencies and vice versa. DRIS reveals not only the limiting nutrient but also the order in which the nutrients are likely to become limiting. It is a comprehensive system which identifies all the nutritional factors limiting crop production and in doing so increases the chances of obtaining high crop yields by improving the fertilizer recommendations. Index values which measure how far particular nutrients in the leaf or plant is deviating from the optimum are used in the calibration to classify yield factors in the order of limiting importance.

To develop a DRIS for a given crop the following requirements must be met.

All factors suspected of having an effect on crop yield must be defined.

1. The relationship between these factors and yield must be defined.
2. Calibrated norms must be established.
3. Recommendations suited to particular set of conditions and based on correct and judicious use of these norms must be continuously refined.

Establishment of DRIS Norms:

Large number of sites is selected at random in order to represent the whole production area. At each site plants and soil samples are taken for all essential element analyses. The entire population of observation is divided into two sub populations (high and low yielders) on the basis of vigour, quality and yield. Each element in the plant is expressed in as many ways as possible. For eg: Nutrient ratios N/P, N/K or products NxP, NxK etc. Each form of expression which significantly discriminates between high and low yielding sub populations is retained as a useful diagnostic parameter. The mean values of all the sites for each of these forms of expression then constitute the diagnostic norms.

NPK requirement of the crop is diagnosed using DRIS chart. The chart is constructed of three axes for N/P, N/K and K/P represented with mean values of the sub populations of the high yielder. The concentric circle can be considered as confidence limits. Horizontal arrows (→) in the inner circle indicate the balance between nutrients. Diagonal arrows indicate ( ) a tendency to imbalance. The inner being set at ± 15% and outer at the mean ± 30% for each expression. Vertical (↓ ↑) arrows representing nutrient imbalance. The arrow notation can be replaced by DRIS indices.

Advantages:

1. The importance of nutritional balance is taken into account.
2. The norms for the elemental content can be universally applied.
3. Diagnosis can be made over wide ranges of stages.
4. The nutrients limiting the yield either through excess or insufficiency can be readily identified.

Indicator plants: Certain plants are very sensitive to deficiency of a specific plant nutrient and they produce specific symptoms which are different from other deficiency symptoms. Thus the deficiency of that element can easily be detected. The indicator plants are the following

Element	**Deficiency indicator plant**
N	Cauliflower, Cabbage
P	Rape seed
K	Potato
Ca	Cauliflower, Cabbage
Mg	Potato
Fe	Cauliflower, Cabbage, Potato
Na	Sugar beet
Mn	Sugarbeet, Oats, Potato
B	Sunflower

Biological methods of soil fertility evaluation:

For calibrating crop response, besides chemical soil test values other procedures are also available. They are

1. Mitscherlich pot culture method
2. The Jenny pot culture test
3. The Neubauer seedling method
4. The Stanford and Dement technique
5. Sunflower pot culture technique for boron
6. Sackett and Stewart technique (*Azotobacter* test for P_2O_5 and K_2O)
7. Mehlich technique for available K_2O
8. Mehlich *Cunninghamella* plaque method for phosphorus
9. The Mulder’s *Aspergillus niger* test for copper and magnesium
10. A – value (tracer technique)

Microbiological methods are

1. **Sackett and Stewart technique**: Used to find out P_2O_5 and K_2O status in the soil judged by colonization of *Azotobacter* in the culture prepared from soil. Three containers having soil culture are used of which one portion is supplied with P_2O_5 another with K_2O and rest with both P_2O_5 and K_2O. The cultures are inoculated with *Azotobacter* and incubated for 72 hrs and growth of colony may be classified as under.

Class	**Growth of the colony**
Class I	Very deficient – None or few small pin head sized colonies are seen.
Class II	Moderately deficient – few colonies
Class III	Slightly deficient – The colonies on unfertilized cultures are equal in number and development.
Class IV	Not deficient – colonies on both fertilized and unfertilized plaques are equal in number and development.

2. Mehlich technique for available K_2O: A small amount of soil is taken in conical flasks in which appropriate nutrient solution is added and then it is inoculated with *Aspergillus niger* and incubated for four days. Weight of mycelial pad and its K_2O content are taken into account.

Critical limits for available K by using the *Aspergillus niger* method

Weight of 4 pads (g)	**K_2O absorbed by *A niger* per 100 g soil (mg)**	**Degree of potassium deficiency**
<1.4	<15	Very deficient
1.4 to 2.0	15 to 20	Moderate to slight deficiency
2.0	>20	Not deficient

3. Mehlich's *cunninghamella* plaque method for P: *Cunninghamella* is sensitive for P_2O_5 status. The soil is mixed with nutrient solution and paste is prepared which is spread in clay dish. Then inoculated with cunninghamella and allowed to incubate for 4-5 days. The diameter of the mycelial growth is considered as an index for P status.

P – deficiency and mycelial growth

Diameter of colonies (mm)	Degree of P deficiency
<10	Very deficient
11-15	Moderately deficient
16-21	Slightly deficient
>22	Not deficient

4. Mulder's *aspergillus niger* test **for Cu and Mg** : Color of the mycelia and spores give an indication of either deficiency or sufficiency of Cu and Mg. For comparison, known standards are prepared as follows and their colors are compared with those on the unknown soil.

Ranges for Cu and Mg in Mulder's test

Cu in µg /g of air –dry soil	Deficiency degree	mg in µg/3 g of air – dry soil
< 0.4	Very deficient	< 50
1 – 1.5	Slightly deficient	50 - 100
>2.0	Not deficient	>100

Pot culture test:-

Besides plant analysis there are some biological tests which may be used to evaluate soil fertility.

1. **The Mitscherlich pot culture method**: In this method pots containing 2.72 kg soil are taken for growing oats as test crop. N, P and K are added in different combinations in these pots [N_o - one pot, P_o - three pots (NK), K_o- three pots (NP) and NPK - three pots)]. The crop is grown till maturity and percentage increase in yield is calculated by using Mitcherlich tables from rotation of given quantity of fertilizers over native fertility status (control).
2. **The Jenny's pot culture test**: Smaller pots consisting of 1.81 kg soil are used for growing

lettuce (*Lactuca sativa* longifolia) as test crops for 6 weeks. Following treatments are used in four replications.

Control	No Po Ko
Full fertilizer	N150 P150 K100
No nitrogen	N0 P150 K 100
No phosphorus	N150 P0 K100
No potash	N150 P150 K0

The percentage values are categorized as deficiency, probable deficiency and uncertain deficiency as mentioned below:

Jenny's values	**% yield**		
	Definite deficiency	**Probable deficiency**	**Uncertain deficiency**
N	20	20-50	51-70
P	20	20-50	51-65
K	70	70-75	76-80
S	66	66-76	77-83

3. The Neubauer's seedling method - In this technique, 100 seedlings of rye or oats are made to feed exhaustively on 100 g of soil mixed with 50 g of sand for 17 days in dishes of 11 cm and 7 cm depth. A blank without any soil also is taken. The total P_2O_5 and K_2O uptake is calculated and the blank value is deducted to obtain root soluble P_2O_5 and K_2O in 100 g of air dry soil. These values are designated as Neaubauer's numbers and expressed as mg/100 g of dry soil. The following Neaubauer limit values are used to determine the deficiency.

Neaubauer limit values mg/100 g soil

Nutrient	Barley	Oats	Rye	Wheat	Turnip	Potato	Sugarbeet
P_2O_5	6	6	5	5	7	6	6
K_2O	24	21	27	20	39	37	25

4. The Stanford and Dement technique: Round waxed cardboard cartons of about 100 g capacity with bottom removed which are nested in similar containers having intact bottom filled with 680 g of sand. The seeds of the test crop are sown about 1.25 cm deep. After growing the seedlings for 2 to 3 weeks, a carton containing the plants are nested in second carton holding 200 g of soil or soil mixed with fertilizers. The plant roots enter the second carton where these plants are allowed to feed for 3 to 5 days. Four plants of maize and 30 plants of wheat are maintained for the study. After 5 days the plant samples are taken to determine the nutrient content.

5. Sunflower pot culture technique for Boron: In this method 500 g soil is taken in small pot and 5 sunflower seedlings are allowed to grow. The soil is fertilized with a solution containing all the nutrients except B and deficiency of B is noticed and ranked.

Class	Days after which B deficiency is noticed
Marked deficiency	< 28
Moderate deficiency	28 – 36
Little or no deficiency	> 36

6. A value: By using radioactive isotopes, it has now become possible to calculate the available nutrients in the soil. Fried and Dean (1952) defined A-value as that amount of nutrients in soil which behave in a similar way as the applied fertilizer nutrient doses. This can be calculated by the formula.

$$A = B\left(\frac{1-y}{y}\right)$$

Where.,

A = Available soil nutrient B = Amount of fertilizer nutrient applied. Y = The fraction of the nutrient derived from fertilizer contained in the plant.

Indicator plants:

Certain plants are very sensitive to deficiency of a specific plant nutrient and they produce specific symptoms which are different from other deficiency symptoms. Thus the deficiency of that element can easily be detected. The indicator plants are the following

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Mn	Sugarbeet, Oats, Potato
B	Sunflower

Soil test based fertilizers recommendation:-

This was put forth by Ramamoorthy (1971). The underlying principle is to get as a large variation as possible in the soil fertility levels in one and the same field in a given locality where an elaborate field experiment is conducted so that the real relationship between the yield and the level of soil fertility could be evaluated without interference from other factors affecting the yield.

A large field of certain amount of natural variation in fertility is chosen. It is divided into four strips which are treated with four different doses of N, P and K viz., control ($N_0P_0K_0$), half of the normal dose ($N_{1/2}P_{1/2}K_{1/2}$), normal dose ($N_1P_1K_1$) and double normal dose ($N_2P_2K_2$) of N, P and K fertilizers that are usually applied to the high yielding varieties of the crops in the country. Exhaustive crop like sorghum, maize, wheat or rice are grown on this field to deplete the soil fertility level in the strips treated with fertilizers. An experiment is then laid out on this field for the purpose of Soil Test Crop Response (STCR) correlation with 21 treatments having different N, P and K randomly arranged in each strip in such a way that there is an untreated check plot on either side of the treated plot.

The soil test crop response correlation work is then carried out taking the yield of treatments and the average of the two controls (check) plots into consideration.

Critical soil test level approach

The critical soil test level, concept advanced by Cate and Nelson (1965) is the level of the nutrient below which a reasonably satisfactory economic response should be expected from the application of that particular nutrient and above which the probability of such response is low. In order to apply this concept, the soil is collected from each field are analysed, field experiments are conducted with application of graded doses of nutrient and response curve is fitted. A scattered diagram of percentage yield on Y-axis and soil test value on X-axis is then plotted. It is divided into four quadrants positioning the lines in such a way that the number of points in the upper right and lower left quadrants is maximum. The point where the vertical line crosses the X-axis is defined as the critical soil test value.

Critical levels of nutrients in soils:

Critical value may be defined as the nutrient concentration below which the plants are expected to respond to the application of that nutrient.

Critical level of micro nutrients in soils

Micronutrient	**Indices**	**Critical level (ppm)**	
		Range	**Mean**
B	**Hot water soluble**	**0.1 – 2.0**	**0.7**
Cu	**Mehlich No.1**	**0.1 – 10.0**	**3.0**
	DTPA + Ca Cl_2 (pH 7.3)	**0.12 – 2.5**	**0.8**

	AB-DTPA (pH 7.6)	**----**	**1.8**
Fe	**DTPA + Ca Cl_2 (pH 7.3)**	**2.4 – 5.0**	**4.0**
	AB-DTPA (pH 7.6)	**----**	**4.0**
Mn	**Mehlich No.1**	**4.0 – 8.0**	**7.0**
	DTPA + Ca Cl_2 (pH 7.3)	**1.0 – 2.0**	**1.4**
	0.03 M H_3PO_4	**0-20.0**	**10.0**
	AB-DTPA (pH 7.6)	**----**	**1.8**
Mo	**$(NH4)_2C_2O_4$ (pH 3.3)**	**0.04 – 0.2**	**---**
Zn	**0.1 N HCl**	**2.0 – 10.0**	**5.0**
	Mehlich No.1	**0.5 – 3.0**	**1.1**
	DTPA + Ca Cl_2 (pH 7.3)	**0.25 – 2.0**	**0.8**
	AB-DTPA (pH 7.6)	**----**	**1.5**

Use of empirical equations for scheduling fertiliser P dosage to crops

Krishnamoorthy et al., (1963) worked out empirical relationships between the nature of the soil and the extractable P. They found that the capacity to fix added phosphates is largely a function of the type and amount of clay present in the soil.

In the case of typical black cotton soil consisting of montmorillonite and beidellite type of clay minerals, the extractability of added phosphates is given by the formula

$$\text{Percentage extractable P} = 100 - \text{Clay percentage}$$

ii) In the case of red and alluvial soils where illite dominates, the relationship appears to be

$$\text{Percentage extractable P} = 100 - 2\,(\text{Clay percentage})$$

Nutrient use efficiency

Nutrient use efficiency (NUE) may be defined as yield per unit input. In agriculture, this is usually related to the input of fertiliser, whereas in scientific literature, the NUE is often expressed as fresh weight or yield per content of nutrient. Improvement of NUE is an essential pre-requisite for expansion of crop production in marginal lands with low nutrient availability. NUE not only depends on the ability to efficiently take up the nutrient from the soil, but also on the transport, storage, mobilization, usage within the plant, and even on the environment.

> Nutrient use efficiency is defined as the extent to which the nutrients and management practices interact to give a specified yield level.

$$\text{NUE (\%)} = \frac{\text{Yield with applied nutrient} - \text{Yield without applied nutrient}}{\text{Amount of nutrient applied}} \times 100$$

Factors affecting NUE

A. **Soil factors**: The most important factors are soil physical conditions, soil fertility and soil reaction. On soils with poor physical condition, plant growth will be poor due to impeded drainage, restricted aeration and unfavourable soil temperature due to which the nutrients will not be used efficiently. Coarse textured soils are usually poorer in available nutrients than fine textured soils. On such soils nitrogen and potassic fertilizers should be more frequently applied than in fine textured soils. The higher the fertility status of the soil, the lower is the response. Soil reaction is an important consideration in the selection of right type of P fertilizers. The higher the organic matter status, the more is the nutrient use efficiency.

B.**Climatic factors**: include temperature, rainfall and its distribution, evaporation, length of day and growing season. Rate of nitrification is slower in cooler climate than in warmer climate, hence more amounts of fertilizers should be added in cool climate. Higher amount of fertilizers are required in high rainfall region due to leaching to obtain an expected yield potential. In arid regions, soil moisture is a limiting factor to get higher nutrient use efficiency. The higher the light intensity, the better is the nutrient use efficiency.

C. **Crop factors**: CEC of plant roots influences the fertilizer responsiveness of the crop. A large ramifying root system of the plant absorbs nutrients more efficiently. The time of application of fertilizer should match the pattern of nutrient uptake to increase nutrient use efficiency. For legumes N fertilizer may be reduced as they can fix atmospheric N to increase N use efficiency.

D. **Agronomic factors**: include selection of fertilizer responsive crops and varieties, timely sowing, proper spacing, proper dose, time and method of fertilizer application to increase the yield and there by increasing NUE.

How to enhance nutrient use efficiency

Use efficiency of any nutrient can be increased by achieving potential yields of crops by optimizing the factors of crop production.

Selection of suitable crops and varieties, which are input responsive recommended for the region.

1. Sowing or planting the crops at optimum time.
2. Maintaining optimum plant population.
3. Use of organic manures and biofertilizers to supplement nutrients and also to bring ideal conditions for crop growth.
4. Inclusion of legumes in the cropping system as intercrop.
5. The crops should be irrigated at least to save life at critical growth stages.
6. Fertilizer scheduling must be based on soil test values to prevent nutrient deficiencies or luxury consumption.
7. P and K fertilizer and part of N fertilizer should be applied as basal and N in splits doses; for light textured soils K also should be applied in splits.
8. Band placement of fertilizers preferable to prevent losses. (Especially P to reduce fixation).
9. Under moisture stress condition, foliar application of urea at 2% concentration is effective.
10. Micronutrient deficiencies should be corrected instantly.

11. $ZnSO_4$ should be applied as package once in two seasons @ 25-50 kg/ha.
12. Problem soils must be ameliorated by taking reclamation measures.

NUE of individual nutrients also can be increased by following the above management practices along with some specific measures as follows

Nitrogen use efficiency: can be increased through

1. Split application of nitrogenous fertilizers to prevent losses due to leaching.
2. The use of slow release nitrogenous fertilizer like urea formaldehyde, sulphur coated urea, Neem coated urea etc.
3. Use of nitrification inhibitor (Eg: N-serve) to retard the conversion of NH_4^+-N to NO_3^--N to prevent leaching and make it available to crops for quite longer period.
4. By the integration of inorganic N with organic sources the soil physical condition can be optimized besides adding nutrients to the soil.

P use efficiency can be increase by decreasing P fixation and balanced application of the nutrients. P fixation can be reduced by judicious application of organic manures, application of P fertilizer by placement, inoculation (either seed or soil) with phosphorus solubilising bacteria like *Pseudomonas*, *Bacillus megathrium* var. *phosphaticum*.

K use efficiency: can be enhanced by preventing leaching loss either by split application on light soils, applying organic manure and balanced application of nutrients.

S use efficiency: Sulphur in soil solution is present as $SO4^{=}$ and more prone for leaching losses. The losses can be prevented by applying organic manures to improve water holding capacity of the soil and it also acts as a source of S. S oxidation can be facilitated by providing oxidized conditions in the soil.

Fe use efficiency: Most available form of iron is Fe^{2+}. All the measures which govern the soil reaction will influence Fe availability. Fe availability is more in acidic soil pH.

- Application of organic manures including greenmanuring improve the use efficiency of iron by
  1. Acidifying the rhizosphere due to the release of organic acids
  2. Supplementing with iron after decomposition

3. Act as substrate for heterotrophic bacteria that can reduce ferric to ferrous form (eg., *Bacillus, Clostridium and Klebsiella* etc.).

4. The microbes also produce chelating ligands called as ‘siderophores’ that can form complex with Fe^{3+}, which can be absorbed into the plant.

5. Reclamation of alkali soils

6. If deficiency appears on standing crop foliar application of Fe.

Zn use efficiency

1. Zn fertilizer should not be applied with phosphatic fertilizers.
2. Maintaining the soil pH between 5.5 – 6.5 by applying organic manures.

Integrated Nutrient Management (INM)

The main challenges facing agriculture planners and farming decision makers in the coming few years' lies in vision world without hunger and zero poverty intensified by rising standards of living of rural regions, where the majority of poor people live and their full dependence on agriculture for living to fulfill their food demands. The key to eliminate the current suffering lies in the creation of a strategic plan that enhances prosperous farming and enables farmers themselves to achieve agricultural growth, reduce poverty, and sustain high returns. Thus, the main challenge in the forthcoming few years lies in the following question. Can agriculture provide the world population with all food needs which are expected to exceed. With the view of an increase in land scarcity and water shortage, most of the agriculture plans depend on the use of chemical fertilizers and the production of new high-yielding crop varieties. Yet, both components are much expensive and will lead to higher pressure and more responsibilities for the financial investments and consequently will lead to an increase in the total costs. Meanwhile, the price of fertilizers increases, year by year, due to the higher amount of fertilizers needed in the second and third seasons as compared with that in the first season to maintain the current yield production at economical level. Despite the increase in the quantity of fertilizer application, a part of applied fertilizers and soil native nutrients were already consumed by the current and previous crops, especially in the case of intensive agriculture, where two to three crops are annually cultivated. Moreover, application of inorganic fertilizers is not a pragmatic option for many poor farmers in different regions worldwide, because many poor farmers do not have enough money to pay the claim of fertilizer price, besides its scarcity and un- availability in times of need.

Since ancient times, farmers have known that soil health can be restored by applying organic manure; accordingly, they used to apply farmyard manure regularly and directly after crop harvest. Consequently, the custom of using organic manures after harvesting has been coupled with restoration of soil health and improvement of physical, chemical, and biological properties of soil, particularly in marginal soils, which are already suffering from low organic matter and low native nutrient content, low productivity, and limitations and unavailability of essential nutrients.

Additionally, the organic farming system provides organic food, which is preferred by many customers regardless of higher prices. In this context, organic fertilizers, also due to their slow release, have greater residual effect on subsequent crops than inorganic nutrient, which is quickly lost by water leaching and run-off to underground water. Recently escalated calls emerged invited farmers and agriculture specialists to change their awareness towards substituting a part of inorganic fertilizers by cheaper, more sustainable, higher nutrient use of efficient, and eco-friendly nutrients, which are originated from natural resources (Compost), under the bold title of using integrated nutrient management (INM).

Under the heading of INM practices, many subheadings can be introduced, including the use of farmyard manures, natural and mineral fertilizers, soil amendments, crop residues, and farm waste recycling, agro-forestry, green manures, and compost. In contrast, some researchers have concluded that the effects of organic manures do not always have positive contribution, and some organic materials may indeed be inhibitory to plant growth, perhaps due to the presence of high levels of phytotoxins and high C/N ratio, particularly in organic materials which are immature.

Thus, the recycling of organic wastes, by the farmers themselves, may be a valuable and acceptable option for many of agriculture planners and numerous farmers to overcome the traditional methods of organic waste disposal, with or without the slight risk to the plants, groundwater or ecological pollution, and human health to achieve the best use of existing natural resources.

The key component of the INM goal is to reach the most effective and homogeneous combination that could lead to good management and be an effective target of the fertilizers, sufficient and balanced use of their quantity and quality, and be straightforwardly up-taken by plants for higher yield without jeopardizing soil native nutrients or polluting the environment. It is ultimately viable to achieve such a target through the wise application of integrated nutrient management (INM) approach, which is known as a balanced mixture of organic, inorganic, and bioorganic microorganisms in combinations in different practices. Also, it can improve all the characteristics of molecule absorption of macronutrients (NPK) and micronutrient inputs. In addition, it can match the crop nutrient requirements and alleviate the constraints of nutrient.

Integrated Nutrient Management refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. deficiency without any harmful effects in the environment and products. In contrary, in the case of mismanagement, it always leads to soil degradation, nutrient deficiency, and quick soil run-off.

Integrated nutrient management is also described as the technique of using minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers in combination with specific microorganisms to make nutrients more available and most effective for maintaining high yields without exposing soil native nutrients and polluting the environment. Furthermore, many benefits can also be gained from using integrated nutrient man- agement. INM can act as the driving forces, able to support the plans of converting marginal lands into productive ones, therefore fulfilling the strategy agenda of increasing cultivated land.

Although many researchers and specialists might find themselves surprised by the results of INM practices, farmers are still in need of great efforts and also additional assistance from many different disciplines, viz., scientific researchers, extension specialists, government sectors, and NGOs, to make them well known and able to recognize whole aspects of such practice, for example, training programs aim at increasing the basic knowledge of plant requirements for the optimum level of yield production. In the same respect, farmers are also in need to know which form of plant nu- trients can be combined with each other to achieve the maximum nutrient-use efficiency and how these supplies can be integrated to obtain highest productivity levels within acceptable economic returns and satisfactory environmental impacts. Also, the integration between different disciplines is also necessary in various spheres, such as plant breeding, agronomy, soil science, plant nutrition, plant protection, and agricultural engineering.

Global food production needs to be increased at least by 70% over the current level by 2050 to meet the increase in food demands, which rapidly increases as a result of overpopulation. To achieve this challenging target, agriculture must grow significantly, in consideration of the factors that contribute to increase the yield production, which are already reduced or tend to reduce, since they are placing unprecedented pressure on the natural resources. Achieving food security is a significant challenge facing agricultural development worldwide in addition to the option of solving highly critical problems to ensure alleviation of poverty. Realizing food security and agriculture sustainability is urgently required; therefore, improving many agronomic approaches, which have drastic effects on crop growth and yield, e.g., soil nutrient content, crop nutrient requirements, and soil nutrient balance, is necessary. Among various practices followed by many farmers, some are in need of some improvement, particularly having bad habits regarding the use of a large amount of fertilizers under the inherited knowledge that without applying a large amount of fertilizers they do not maintain high yields. Such irresponsible practices, which are accepted by many farmers, result in the loss of most fertilizers applied and cause some environmental problems and raise the overall costs. Moreover, continuous use of synthetic fertilizers generates serious problems of soil nutrient deficiency and food contamination and damages soil physiochemical properties through the increase of soil acidity, which leads to hasty deterioration soil health, productivity, and both stability and sustainability.

In spite of the fact that the application of chemical fertilizers has more advantages than disadvantages, it does not always mean that an increase in crop production must be obtained after their application, because a part of the added fertilizers may not be utilized by crop, as it may temporally remain in the soil or may be lost through volatilization or by leaching to underground water and then result in serious problems and dangers and becomes a source of environmental pollution. Considering the abovementioned reasons and in addition to high costs and declining profitability, scarcity, and leaching down to the root zone, groundwater contamination becomes the cause of diseases. Recently, farmers and agricultural specialists recognize that further application of inorganic fertilizers does not mean that an increase must be induced, and then they realize the importance of soil fertility through the application of organic fertilizers, that are available and inexpensive and can be used solely or in combination with other available organic or inorganic resources to enhance the soil fertility and bring about higher crop production, without having any undesirable impacts on the environment. Concerning the basic materials which can be used in the INM system, several investigators discovered that various materials can be used as a constituent of INM combinations, viz., farmyard manures, natural and mineral fertilizers, soil amendments, crop residues and farm waste recycling, agro-forestry, green manures, and compost. Such materials are generally seen as a key practice in the eco-friendly system to ensure sustainable production and safety food production. However, recycling of organic wastes into compost is a complex field practice that needs more labours and may lead to raise the labour and total costs. Yet, in comparison with the many gains that can be attained in the long run such as improving the soil health, ensuring safety of the food produce to guarantee that the environment will become satisfactory and acceptable technique for many farmers, agriculture specialists and agriculture planners alike. Thus, the application of organic fertilizers leads to restoration of the soil health and maintains the productivity for long period; regretfully at field scales, the sole application of organic fertilizers to sustain the crop yield at economic level cannot be reliable. Therefore, it must be applied in combination with other fertilizers, which are derived from inorganic sources to meet the crop nutrient requirements. Currently, the goal of interests of most researchers needs to be modified; the main issue of the most critical researches must be included in managing nutrient programs to provide a safe food supply free from pollutants or at least which contains minimum level of agrochemical contaminants, furthermore guaranteeing an environment without pollution or at least a lower level of pollution which is one of the huge challenges of the 21st century. Therefore, the great challenges have been to optimize the nutrient supplies to maintain high nutrient-use efficiency, refine the natural resources, modify the agriculture practices to achieve more grain yield per unit area, without jeopardizing the soil and natural resources, and improve the water use efficiency to produce more crops per drop. All of these are the most important goals, which can be achieved by the implementation of INM program not only at the present time but also in the near future. Integrated nutrient management (INM) is a scheme that refers to a safest way to dispose off crop residues and produce high-quality compost by a balanced and integrated use of both sources of fertilizers together in combinations (organic and inorganic fertilizers) for maintaining soil fertility and providing plants with an optimum level of nutrients required over all of cycle life to sustain the yield productivity. The key component of INM system includes the following items:

(1) Considerable attention must be focused on all possible nutrient sources that can be used as a tool of nutrient sources in planning nutrient input programs for optimizing nutrient-use efficiency and high yield production

(2) The forms and quantities of soil nutrient contents in the root zone, which is known as soil balance and its availability to cover crop requirements (spatially and temporally)

(3) Minimizing nutrient losses, especially in the intensive agriculture system.

(4) Taking all factors affecting the plant/nutrient relationship into consideration to achieve high yield production, which is the main objective and the major gain of the application of integrated nutrient management (INM), water use efficiency, grain superiority, high economic return, and sustainability.

Definition of Integrated Nutrient Management:

Integrated nutrient management is a practice where all sources of nutrients namely organic, inorganic and biofertilizer can be combined use for improving soil health, get good quality yield and maintain ecology and environment. or

Integrated nutrient management mean combined application of different sources of plant nutrients like organics, inorganics and biofertilizers for sustainable crop production without degrading the natural resources on long terms basis.

1. Concepts:

Integrated nutrient management is a practice that combines old and modern techniques of fertilizer use and nutrient management. The idea of INM depends on a number of factors, including harmony in nutrient properties, a balance between crop nutrient demands, what sort of nutrient, in general, is available in soil and in the farmer’s hand, information and skills about the most suitable nutrient can be harmonized in combination, and which materials can be safely used that lead to increase nutrient-use efficiency. Additionally, it is a method and a way of disposing organic wastes safely and also an effective method of recycling wastes into good quality compost. The key components of the INM concept include the following: increasing the farmer’s awareness about the valuable use of INM practices, inviting them to forget the excessive use of chemical fertilizers, and encouraging them to focus on long-term plan for sustainable agriculture. Moreover, farmers must have greater consideration for environmental impacts and producing safety food rather than only focusing on profit, which can be obtained. It must always be remembered that food safety is much preferred by many customers, regardless of the price, and it can raise the farmer’s returns by following such practices.

2. Objectives:

The main objective of the integrated nutrient management is to maintain economic yield for a long period with little effect on native soil fertility and environmental pollution, making some changes in farmer’s awareness toward the eco-friendly technique (organic farming system) for producing healthy food free from contaminants and insuring satisfactory economic returns.

3. Constraints:

Soil corrosion, mining, degradation, and also loss of fertility are the main reasons leading to irreversible decrease of plant production and huge damage for sustainable agriculture. Therefore, to sustain soil health and return soil productivity is an urgent need to overcome the problem of low soil productivity. Serious efforts have been made including the promotion of more productive use of integrated nutrient management, which is an inessential portion in the organic farming system. In addition, considerable attention must be given to determine soil nutrient balance including nutrients absorbed by the current crop accompanied by great attention towards the requirement of the succeeding crop. +us, continual assessment of the changes in the current soil fertility is necessary to determine nutrient loss through crop absorption, erosion, and leaching and to mirror soil balance, because quick depletion of soil fertility and reduction in soil organic matter will be expected. Additionally, there are some constraints facing the progress of the integrated nutrient management. Firstly, due to the difficulties in obtaining FYM and biofertilizers, some poor farmers have some trouble in obtaining organic manure as well as lack of knowledge, poor advisory services, and skills of recycling organic wastes to produce high-quality compost. Also, biotic or abiotic stresses are ranked to second series and the third will be the poor tillage, whereas the lack of equipment was ranked in the fourth succession. Also, the absence of the role of extension services and NGOs to support farmers and direct their attention to the importance of using integrated nutrient management and its benefits in conserving soil properties, soil nutrient balance, environmental impacts, and their role in increasing their profitability is a constraint.

4. Advantages:

Preparing the soil for producing its maximum capacity is an important target and a complex process resulting from the solidarity of many factors, which largely depend on more than one factor to get the best benefits, among others, soil nutrient content which must not only be in an appropriate and accurate quantity but also be in an easy and available form for plant absorption at the right time of plant requirement. +us, a good nutrient management package is a way to attain ideal growth and yield levels for most crops at different agro-ecological zones, with or without minimum risk in the environment (eco-friendly strategy). This can also be described as a system involving a series of the following benefits:

(1) Systems can improve the soil nutrient natives and increase the solubility and availability of fertilizers to be used.

(2) Use the harmonious behavior of nutrient supplies and making them match with the crop requirements.

(3) Offer the nutritional balance to the crops and lessen the aggressive effects resulting from the opposite impact between nutrient fractions and nutrient imbalance.

(4) Advance and sustain the physiochemical and biological functions of soil properties

(5) Reduce the rate of soil degeneration, water, and ecosystem by enhancing carbon confiscation and decreasing nutrient losses to ground and surface water forms and/or to environment pollution.

(6) Minimize higher total costs of production and raise the farmer's returns (increasing profitability).

(7) Improve the resistance to both biotic and abiotic stresses.

(8) An effective method of agricultural practices to ensure healthy food, covering population food demands alongside with many soil and environmental impacts, especially in countries with rapid growth in population.

(9) Additional benefits can also be gained; it does not only save the total costs at the satisfactory level with an increase in crop production but also can be easily practiced by farmers; therefore, it is considered one of the most promising techniques in line with the future needs.

(10) INM can have positive effects on the susceptibility or plant resistance against many types of biotic and abiotic stresses.

(11) Following INM will enable to explore a larger volume of soil in order to access water and nutrients; additionally, improved root development enables the plant to absorb water from deeper soil layers and then reflect an increase in the ability of crops toward drought resistance.

(12) Changes in awareness of farmers toward the climate changes from season to season, which have greater ecological impacts in order to produce safe food rather than achieving higher yield aiming at attaining higher profit.

5. Relationship between INM and the Effect of a Number of Factors on Sustainable Agricultural Production

5.1. Integrated Plant Nutrient Management in Relation to Macro and Micronutrients.

Generally, most of the major studies regarding the effect of the application of macronutrients (NPK) are mainly focused on testing the rate of application, timing of application, varietal responses, and the effect of its integration with numerous agronomic practices. However, most of the studies related to the effect of micronutrient application have focused on yield quality traits or may also include methods of application, suitable for treating the problems of micronutrient deficiency. Most of these studies suggested that application of the recommended dose of inorganic fertilizers is more important than being neglected in order to maintain the economic yield, especially in low-fertile soils. Whereas the other investigators reported that, occasionally, the application of inorganic fertilizers may be the reason for prolonging growth period and also may be the cause of delayed flowering and physiological maturity by 1-2 weeks and will lastly lead to a decrease in yield quantity and quality. Above all, imbalanced and continuous use of inorganic fertilizers may result in some problems in micronutrient deficiencies, which become major constraints on productivity, stability, and sustainability of soil health. Therefore, INM becomes one of the most principle practices, which can replace the traditional methods, decreasing the nutrient losses and their harmful effects on the environment, while maintaining higher crop yield and advanced profits. Considerable attention to the success of INM is related to the selection of a combination, which can provide plants with different nutrient sources in adequate amount at intervals agreeable with the plant requirements and also which plays a vital role in improving the nutrient-use efficiency and can achieve higher yields. Also, integrated nutrient management practices may be the best way or dominant option for harmonizing the utilized totality of the farm wastes that can be used as plant nutrients. In addition, it is not only the most effective practice that can prevent nutrient deficiency but also strongly related to social issues, especially for poor farmers, who are unable to spend large investments in maintaining the soil fertility. Although the combination of organic fertilizers with inorganics considered a stock of nutrients which can continuously supply the current crop with their requirements, it can also be considered as a scheme which has greater residual effect on subsequent crops than sole application of inorganic fertilizers, due to slow release of nutrients over time and its added value in soil organic matter content. In addition, most of current literature revealed that significant attention has been paid to determine the role of integrated nutrient management of organic and inorganic fertilizers on growth and yield, including the use of FYM, green manures, and biofertilizers. on a long-term field experiment found that the continuous application of inorganic fertilizers alone reduces the soil organic carbon level due to low dry matter production and leads to reduction in the return of crop residues to the soil. Keeping these aspects in mind, excess or lack of essential nutrients (N, P, K, S, Ca, and Mg) and micronutrients is often called “limiting factors” because each one could limit the plant growth and cause serious problems in most of the accumulation processes of making the use of integrated nutrient management an essential factor and a main reason leading to sustainable agriculture. Lastly, farmers and researchers cannot neglect the role of the soil microorganisms in controlling nutrient conversions, solubility, availability, release from the soil root zone to plant roots, and also the role in absorption and raising nutrient-use efficiency, which can be achieved by following the INM system. An additional trend was also observed, a decrease in the losses of water and nutrients through leaching, runoff, volatilization, emissions, and immobilization, which resulted from an increase in the soil organic matter contents and improvement of soil physical and hydrological properties.

5.2. Integrated Plant Nutrient Management in Relation to Environmental Concern and Food Requirements.

Since the early times of the 1990s, the increase of agricultural production for main food crops has been increasing or even tended to decrease, whereas the trend for global food production needs to increase to above 4 billion metric tons by 2050 to cover population needs which are rapidly increasing. However, further increases in the farming production have been associated with negative impacts on global change, water scarcity, land degradation, erosion, and soil nutrient balance besides depletion of soil organic carbon and later soil runoff. Agricultural approaches are the largest contributors to these emissions. Tremendous increase, which has rapidly emerged in the recent years, is mainly due to the huge use of synthetic fertilizers and pesticides, especially in the case of the intensive agricultural system. Thus, the use of chemical fertilizers particularly nitrogen, phosphorus, and potassium (NPK) is the essential factor and main reason leading to environmental pollution and land erosion because of their perpetual uses for long time in some developing countries. In addition, the consumption of synthetic fertilizers has risen globally by 49%, 19%, and 33% for nitrogen, phosphorus, and potassium, respectively. Some of the current investigations reported that the intensive use of synthetic fertilizers and pesticides did not have a significant contribution in the yield increase; this may be due to more than one factor, viz., great nutrient losses through leaching, runoff, volatilization, and releases and immobilization or may be owing to low nutrient-use efficiency. Thus, the reverse habits are necessary and also are essential in devising an agriculture strategy plan to find out a way that enables to produce higher yield production for long-term periods, encourages conservation natural resources, ecological impacts, and global climate change alleviation and adaptation, also matching with the other agricultural programs aiming at increasing the production and ensuring the environment. Accordingly, it is high time to search for innovative practices which can guarantee higher yield productions with or without minimal risks or further deterioration of our environment. INM technique can thus play this role and remain the most effective way to achieve the food security, improve the environmental quality, and meet the growing food demand worldwide without any bad effects, especially in countries having rapid growth population. Integrated nutrient management (INM) is also a practice that has much significantly shown impacts by decreasing the chemical application through a combination of inorganic and organic fertilizers either with or without biofertilizers that could minimize the nutrient applications and then lessen their nutrient requirements, reduce food contamination. Lastly, INM is a simple system that can create a favourable soil condition, able to provide plants with sufficient, efficient, and sustainable nutrient source and also is a promising strategy that has made considerable contributions to lessen the negative environmental impact, boost both the quantity and quality traits of the global food supplies, and increase the land expansion with the plan of sustainable and economical agricultural development.

2.2.3. Integrated Plant Nutrient Management in Relation to Soil Structure and Water Use.

Recently, many findings highlighted that the relationship between soil structure and water conserving or water uses liner and largely depends on many factors, among these, soil organic matter, both quality and quantity, due to the fact that soil organic matter is considered the primary peacekeepers of most of soil properties, which are the bases of soil quality physically (structure), chemically (nutrition), and biologically (microorganisms). Therefore, any further improvement in soil structure creates a favorable condition for plant water relationship without having any undesirable impact on the environment, for example, integrated nutrient management can improve the soil organic carbon, which is an important indicator of soil structure and can directly indicate the state and type of soil quality and soil fertility and is also a proof of the possibility of agriculture sustainability due to the sunny roles in improving the soil physical properties, viz., nutrient availability, moisture retention, cation-exchange capacity, soil pH, microbial community and activity, bulk density, and aeration. Whereas other studies reported that application of organic manures with chemical fertilizers through integrated nutrient management system has an effective role in improving the physiochemical soil properties, that leads to an improvement in water infiltration, water-holding capacity, and water flow down and increase in soil field capacity, which consequently improve the economic water use and water use efficiency and leads to more water conservation without reversible effects on crop productivity. In addition, further improvement in soil pH creates a favorable condition for macro- and micronutrient absorption. Recently, noticeable quantitative and qualitative changes in field management practices are particularly related to the use of organic manure and chemical fertilizers along with biofertilizers. These changes are generally beneficial for improving the physical, chemical, biological, and hydrological properties of the soil, which are reflected in a significant rate in mitigation; the irreversible adverse effect of the drought stress make up a significant portion of water conservation and soil degradation and the main effect may be updegraded soil class. In the same respect, previous studies indicated that high attention must be given on the fact that some fields have poor response to nutrient unsystematic application of fertilizers.

5.4. Integrated plant Nutrient Management in Relation to Plant Growth and Crop Yield.

Plant growth is influenced by many factors, e.g., application of the recommended and ideal dose of inorganic and organic fertilizers, which is an essential option and important factor for enhancing the crop growth and nutrient uptake as well as a vital component in supporting the crop life cycle and yield potential. Therefore, superfluous additions of fertilizers does not always mean that an increase in crop production must occur; a part of added fertilizers may be not absorbed by the crop and mostly remain in the soil or may be lost through volatilization or by leaching to underground water, and then become dangerous and a source of environmental pollution. Several investigations indicate that INM has remarkable benefits and play a potential role not only on crop growth but also on sustainable development of agriculture involving environmental impacts. It is well known that a rapid decline in soil fertility which leads to low productivity is related to many factors and occasionally closely linked to irresponsible practices followed by farmers, among these, continuous and intensive use of the cropping system, excessive use of chemical fertilizers, and negligence of soil nutrient balance in planning agriculture programs, and intensive cultural practices and ignoring the application of organic manures solely or in combination with inorganic fertilizers. Therefore, when managing the agriculture strategy, significant attention must not only be given to fertilization programs only but also to the sources of nutrients which are matching, homogeneous, and mixed in such a combination that they are available for plant absorption and cover all of the crop needs. Success of INM relies on a number of factors, including appropriate right combination, right dose, and right form and application at right time of plant need. The integrated use of organic, chemical, and biofertilizers also has an effective role in improving the soil properties, enhancing the nutrient-use efficiency, decreasing the nutrient loss, minimizing the crop nutrient requirement, and increasing the cation exchange, water storage capacity, and service in sustaining higher yield, and improving the phytoavailability of micronutrients in soil and their uptake by plants. All of these may also work together and play a notable role in crop quality. In addition, having an effective role, in general, on plant vigor contribution, particularly which are related to root development, water and nutriment uptake, and dry matter accumulation. CGR, which directly have positive effects in raising the crop productivity per unit area and consequently leading to an increase in water use efficiency, water conservation, and economic water use. Owing to the effect of INM on most of crop growth parameters, high crop yields can be achieved even without further application of NPK rates above the recommended dose of the home-grown area. In this domain, strong and conclusive indication reported previously by many researchers indicate that INM practice can be an effective practice and eco-friendly approach to produce greater yield production and maintain satisfactory profitability to farmers.

5.5. Integrated plant Nutrient Management in Relation to Succeeding Crops.

The bulk of the literature highlighted that long-term use of organic and inorganic fertilizers in combination with biofertilizers indicates a better and effective option to get maximum benefits from the soil to the current crops and occasionally may be extended to the succeeding crop. Many results also concluded that the residual effect of the bioorganic farming system may double the yield of subsequent cereal crops. Furthermore, the papers suggested that INM is an important tool for assessing the nutrient reserve in soils, restoring the soil health, and the most effective management strategy to advance the biological and physiochemical properties of soil, which are vital components in assessing yield and yield contributing components of both preceding and succeeding crops. Such an effect on soil biological properties may be due to the role of microorganisms not only in increasing nitrogen fixation but also in improving the availability and mobility of phosphorus, potassium, and iron, thus providing the plants with essential components needed for the process of plant development and yield productivity while remediating the soil structure by improving its accumulation and constancy.

6. Main Values of Integrated Nutrient Management.

The points below are considered the main principles of INM to be considered in planning the integrated nutrient management strategies:

(1) Adopting INM practices must be compatible with the local farming system, for example, field biological condition (weeds, insects, and diseases), soil texture, irrigation services, and equipment's available and climatic conditions.

(2) Using both sources of nutrients optimizes fertilizer input, increases the use efficiency by crops and then lessens their nutrient requirements and reduces food contamination, environmental pollution, and total costs.

(3) Corresponding soil nutrient supplies with crop demand spatially and temporally in order to conserve native soil contents.

(4) INM practice reduces the fertilizer loss, improves the crop potential, and increases the profitability.

(5) In long term, it improves the physiochemical properties of the soil (biological and hydrological properties).

(6) Applying INM practice on root zone, where the most important process between plant and soil occur, is a "bottleneck" controlling nutrient conversions, solubility, availability, and release from soil to plant roots and absorption. Such an exercise can respond to maximize the biological potential through enhancing the soil microorganism's activity.